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This is the seventh compilation of annual reports for the Navy's ELF Communications System Ecological Monitoring Program. The reports document the progress of eight studies performed during 1988 at the Wisconsin and Michigan Transmitting Facilities. The purpose of the monitoring is to determine whether electromagnetic fields produced by the ELF Communications System will affect resident biota or their ecological relationships.

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A. Tree and Herbaceous Plant Cover Studies
Michigan Technological University
Becker, K. T.; Brooks, R. H.; Bruhn, J. N.; Cattelino,-P. J.; Desanker, P.; Fox, K. B.; Gale, M. R.; Holmes, M. J.; Larsen, G. W.; Liechty, H. O.; Moore, J. A.; Mroz, G. D.; Reed, D. D.; Reed, E. J.; Richter, D. L.; Wu, Y.; Zhang, Y. F.

B. Litter Decomposition and Microflora
Michigan Technological University
Bagley, S. T.; Bruhn, J. N.; Pickens, J. B.

FOREWORD

The U.S. Navy is conducting a long-term program to monitor for possible effects from the operation of its Extremely Low Frequency (ELF) Communications System to resident biota and their ecological relationships. The program is being implemented by IIT Research Institute (IITRI) under contract to the Space and Naval Warfare Systems Command (SPAWAR). IITRI provides engineering support and coordinates the efforts of investigators. Monitoring projects are being carried out through subcontract arrangements between IITRI and study teams at several universities.

This is the seventh compilation of annual reports prepared by university study teams. Each report chronicles the data collection and data analysis activities for a monitoring project during 1988. As in the past, each report has been reviewed by four or more scientific peers. Investigators have considered and addressed peer critiques prior to providing their reports for the compilation, and each report has been printed without further change or editing by either SPAWAR or IITRI.

During 1987, data collection was concluded for studies of wetland biota and slime molds, with the overall findings of each study to be documented during the following year. Documentation of the results for these two projects, previously presented as part of the compilation of annual reports, will be made available as separate reports.

Reports other than this compilation chronicle electromagnetic exposures at study sites or summarize the overall technical progress of the program. A listing of all reports prepared since the inception of the program in 1982 appears immediately following the index of 1988 annual reports. All reports have been provided to the National Technical Information Service for unlimited distribution.

ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM

INDEX OF 1988 ANNUAL REPORTS

A. Tree and Herbaceous Plant Cover Studies
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ECOLOGICAL MONITORING PROGRAM

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Compilations

1. Compilation of 1987 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06595-2, 1988. Vol. 1, 706 pp.; Vol. 2, 385 pp.; Vol. 3, 491 pp.

2. Compilation of 1986 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-38, 1987. Vol. 1, 445 pp.; Vol. 2, 343 pp.; Vol. 3, 418 pp.

3. Compilation of 1985 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-26, 1986. Vol. 1, 472 pp.; Vol 2, 402 pp.; Vol. 3, 410 pp.

4. Compilation of 1984 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-17, 1985. Vol. 1, 528 pp.; Vol. 2, 578 pp.

5. Compilation of 1983 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-8, 1984. Vol. 1, 540 pp.; Vol. 2., 567 pp.

6. Compilation of 1982 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06516-5, 1983, 402 pp.

Electromagnetic Engineering

7. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1988. IIT Research Institute, Technical Report E06595-5, 1989, 69 pp. plus appendixes.

8. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1987. IIT Research Institute, Technical Report E06595-1, 1988, 54 pp. plus appendixes.

9. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1986. IIT Research Institute, Technical Report E06549-37, 1987, 52 pp. plus appendixes.

10. Brosh, R. M.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1985. IIT Research Institute, Technical Report E06549-24, 1986, 48 pp. plus appendixes.

11. Brosh, R. M.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Measurement of ELF Electromagnetic Fields for Site Selection and Characterization--1984. IIT Research Institute, Technical Report E06549-14, 1985, 37 pp. plus appendixes.

12. Enk, J. O.; Gauger, J. R. ELF Communications System Ecological Monitoring Program: Measurement of ELF Electromagnetic Fields for Site Selection and Characterization--1983. IIT Research Institute, Technical Report E06549-10, 1985, 19 pp. plus appendixes.

Program Summaries

13. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1987 Progress. IIT Research Institute, Technical Report E06595-3, 1989, 64 pp. plus appendixes.

14. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1986 Progress. IIT Research Institute, Technical Report E06549-39, 1987, 63 pp. plus appendixes.

15. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1985 Progress. IIT Research Institute, Technical Report E06549-27, 1986, 54 pp. plus appendixes.

16. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1984 Progress. IIT Research Institute, Technical Report E06549-18, 1985, 54 pp. plus appendixes.

17. Zapotosky, J. E.; Abromavage, M. M.; Enk, J. O. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1983 Progress. IIT Research Institute, Technical Report E06549-9, 1984, 49 pp. plus appendixes.

18. Zapotosky, J. E.; Abromavage, M. M. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Plan and Summary of 1982 Progress. IIT Research Institute, Technical Report E06516-6, 1983, 77 pp. plus appendixes.

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: TREE AND HERBACEOUS PLANT COVER STUDIES

The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1988

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INTRODUCTION

Forest vegetation is the dominant cover type on the ELF Communications Antenna System area. In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic fields cause changes in forest productivity and health. Work elements were initiated at control, antenna and ground treatment plots to establish a baseline of data that could be used to compare various aspects of these communities both before and after the antenna becomes activated. This approach is the most rigorous for evaluating possible effects of ELF fields on forest ecosystems.

This year marks the fifth year of actual data collection and evaluation for most elements with initial year's efforts directed toward site selection and experiment development. In these past five years, there have been shifts in work emphasis as promising research areas are explored and others are deemphasized or eliminated. Such is true of this past year. For the first time, there will be no report on the element dealing with herbaceous plant cover research. (This is not to be confused with the herbaceous phenology research which is showing excellent progress). This work was eliminated from the renewal proposal for FY 1988 to 1994 after repeated measurement difficulties and constructive criticism of reviewers. Last year's report documents the limited sensitivity of the analyses used in this phase of study.

A rapidly emerging area of research grew out of initial studies of mycorrhizal fungi sporocarp collections. The increasing incidence of fruiting bodies of at least one member of the *Armillaria mellea sensu lato* species complex (Wargo and Shaw III, 1985) offered an opportunity to quantitatively evaluate forest health interactions with ELF fields at the sites. This pathogenic fungi, which thrives on the stumps and root systems of hardwoods in the red pine plantations, will colonize and kill red pine seedlings. Since the overall objective of the Upland Flora research program is to evaluate the effects of ELF fields on both forest productivity and health, it has become imperative to increase our research effort on this important pathogen.

Because of continued difficulties with the low level of sensitivity of the sporocarp study as originally proposed, it has been deemphasized in favor of increased effort on *Amillaria* studies. This work was outlined in our renewal proposal but is progressing at a faster rate than originally planned due to increasing mortality of red pine due to *Armillaria*. While it is highly unlikely that the disease will have a serious effect on other Upland Flora studies, increased effort on the ELF field-forest health interactions is clearly warranted to meet our overall project objective of assessing the impact of ELF fields on forest productivity and health.

To accomplish this, more specific objectives of the work elements are to determine the impacts of ELF electromagnetic fields on:

1) growth rates of established stands; individual hardwood trees and red pine seedlings;
2) timing of selected phenological events of trees, herbs

and mycorrhizal fungi;
3) numbers and kinds of indigenous mycorrhizae on red pine seedlings;
4) foliar nutrient levels of hardwoods and red pine;
5) foliage production in hardwoods,
6) insect and disease status of hardwood and pine stands.

Ultimately, the question of whether ELF electromagnetic fields measurably impact forest communities will be answered by testing various hypotheses (Table 1) based on the results of long-term studies.

PROJECT DESIGN

Overview of Experimental Design

Much of the effort in this study has been dedicated to developing a statistically rigorous design to separate what may be very subtle ELF field effects on response variables from the existing natural variability caused by soil, stand and climatic factors (Mroz etal. 1985). Consequently, to test our hypotheses it has been imperative to directly measure both plant growth and important regulators of the growth process such as tree, stand, and site factors in addition to ELF fields at the sites (Table 2). These measurements and associated analyses are discussed more fully in the various work element sections of this report. Work elements group similar measurements and analyses but are interrelated, with data from several elements often used to test a single hypothesis (Table 2).

The experimental design integrates direct measures with site variables and electromagnetic field exposure and is a common thread through nearly all studies due to the field design. An understanding of this experimental design is essential because of the similarity in analyses for hypothesis testing and the complexity of the overall project. The rationale and progress for measurements in each work element of this study are unique and will be presented separately.

Field Design

The electromagnetic fields associated with the ELF system will be different at the antenna and ground locations (Anonymous, 1977). As a consequence, forest vegetation at each site could be differentially affected by both above and below ground fields. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at the ground terminal, and at a control location some distance from the antenna.

The experimental design is best described as a split plot in space and time. Each site (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two subunits (hardwood stands and red pine (*Pinus resinosa* Ait.) plantations) (Figure 1). These stand types

Table 1. Critical hypotheses that will be tested to fulfill the objectives of the ELF environmental monitoring program Upland Flora project.

I.	There is no difference in the magnitude or the pattern of seasonal diameter growth of hardwoods before and after the ELF antenna becomes activated.
II.	There is no difference in the magnitude of diameter growth of red pine seedlings before and after the ELF antenna becomes activated.
III.	There is no difference in the magnitude or rate of height growth of red pine seedlings before and after the ELF antenna becomes activated.
IV.	There is no difference in the rate of growth and phenological development of the herb, *Trientalis borealis* L., before and after the ELF antenna becomes activated.
V.	There is no difference in sporocarp production by mycorrhizal fungi before and after the ELF antenna becomes activated.
VI.	There is no difference in the number of different types of mycorrhizal root tips on red pine seedlings before and after the antenna becomes activated.
VII.	There is no difference in the total weight and nutrient concentrations of tree litter before and after the ELf antenna becomes activated.
VIII.	There is no difference in the foliar nutrient concentrations of northern red oak trees or red pine seedlings before and after the ELF antenna becomes activated.
IX.	There is no difference in the rate of development of *Armillaria* root disease on red pine seedlings before and after the ELF antenna becomes activated.

Table 2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Upland Flora project, the objective it is related to, and the work elements addressing the necessary measurements and analyses.

Hypothesis Number	Related Objectives	Measurements	Work Elements
I	1,2	*Weekly dendrometer band readings** climatic variables, soil nutrients, tree and stand characteristics.	1,2,3
II	1	*Annual diameter growth*, terminal bud size, plant moisture stress, microsite climatic variables, number of mycorrhizae.	1,2,3,5
III	1,2	*Weekly height growth, annual height growth*, terminal bud size, plant moisture stress, number of mycorrhizae, ambient measures.	1,2,3,5
IV	2	Periodic measures of plant dimensional variables including *leaf size* and phenological stages of *flowering, fruiting,* etc., climatic variables.	1,3
V	2	*Bi-weekly sporocarp counts by species,* climatic variables.	1,4
VI	3	*Monthly counts of mycorrhizal root tips by type,* climatic variables, tree variables.	1,5
VII	5	*Periodic collections of litter, nutrient analyses,* climatical variables.	1,6
VIII	4	*Periodic collections of foliage, nutrient analyses,* climatic variables.	1,6
IX	6	*Monthly inventory of red pine mortality caused by Armillaria root disease,* soil texture, bulk density and rock content; hardwood stump characteristics and density.	2

*Italicized print designates response variables; others listed are covariates.

comprise the treatments for the second level of the design. Each stand type is replicated three times on a site (ELF field exposure) to control variation that may occur due to such factors as soil, stand conditions and background and treatment electromagnetic field levels. The time factor in the design is the number of years that an experiment is conducted for baseline to treatment comparisons, or the number of sampling periods in one season for year-to-year comparisons. It is necessary to account for time in the experimental design since successive measurements are made on the same plots and individual trees over a long period of time without rerandomization. A combined analysis involving a split plot design is made to determine both the average treatment response (site difference) over all years and consistency of such responses from year to year (Steel and Torrie 1980).

Each site follows this design with one exception. There is no hardwood stand at the antenna ground because required buffer strips would have resulted in the stands being too distant from the ground for sufficient exposure to ELF fields. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. In those cases where measurements are made on only one stand type, it becomes irrelevant and is not included in the analysis. All other factors remain unchanged.

Figure 1. Diagram of the control plot as an example of the experimental design units.

Control Site

(Whole Unit)

Plot 1	Plot 2	Plot 3	(Subunit) Hardwood Stand

sham right of way

Plot 1	Plot 2	Plot 3	(Subunit) Red Pine Plantation

Analysis of Covariance

Our experimental design directly controls error in the field to increase precision. Indirect or statistical control can also increase precision and remove potential sources of bias through the use of covariate analysis. This involves the use of covariates

which are related to the variable of interest. Covariate analysis removes the effects of an environmental source of variation that would otherwise contribute to the experimental error. The covariate need not be a direct causal agent of the variate, but merely reflect some characteristic of the environment which also influences the variate (Cochran 1957). Thus, determining covariates which are both biologically meaningful as well as independent of treatment effects continues to be one of the most important steps in our analysis.

Covariates under examination vary for a given variable of interest (Table 2). Most analyses use ambient climatic variables, such as air temperature, soil temperature, soil moisture, precipitation, and relative humidity, as well as variables computed from these data, such as air temperature degree days, soil temperature degree days and cumulative precipitation. Depending on the variable of interest, microsite factors will also be considered. Other factors considered are more specific to the variable; for example, covariates in the analysis of red pine height growth would include bud size, seedling diameter, and total height of the seedling at the beginning of the study in addition to ambient factors. Analyses are being conducted to determine which of these are both statistically significant as well as biological meaningful without violating the necessary assumptions of treatment independence required for the analysis of covariance (Cochran 1957). The most general and encompassing ANOVA table for the project is shown in Table 3. More detailed ANOVA tables can be found in each work element section of this report.

Testing for ELF Field Effects

Since the antenna was activated for low level testing throughout the growing seasons of 1987 and 1988, hypothesis testing will examine differences in response variables between these and previous years, and differences between control, antenna and ground sites in 1987 and 1988. Testing varies by element with those elements dependent on soil or foliar chemical analyses generally dealing only with 1987 data at this time. This is due to the lag time in laboratory analyses. If there are no differences between 1987 and 1988 and previous years, no differences between sites in 1987 or 1988, and/or differences between sites is stable before and during 1987 and 1988, the indication is that the antenna operation had no detectable effects on the response variable. Methods are being developed to incorporate appropriate measures of exposure levels into the analyses.

Detection Limits

Detection limits for the individual response variables are described in the following work elements. These limits are the amount that a response variable would have to change to be detectable 50 percent of the time (using a significance level of $p=0.05$ unless otherwise noted) given the statistical design and

Table 3. Generalized analysis of variance table for the trees and herbaceious plant cover study.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Covariates	# Covariates			
Plot	2	SS_P	MS_P	$MS_P/MS_{E(S)}$
Site	2	SS_S	MS_S	$MS_S/MS_{E(S)}$
Error (S)	4-# Covariates	$SS_{E(S)}$	$MS_{E(S)}$	
Stand Type	1	SS_T	MS_T	$MS_T/MS_{E(ST)}$
Site x Stand Type	2	SS_{ST}	MS_{ST}	$MS_{ST}/MS_{E(ST)}$
Error (ST)	6	$SS_{E(ST)}$	$MS_{E(ST)}$	
Years	#yrs-1	SS_Y	MS_Y	$MS_Y/MS_{E(SY)}$
Site x Years	(2)(#yrs-1)	SS_{SY}	MS_{SY}	$MS_{SY}/MS_{E(SY)}$
Error (SY)	(2)(2)(#yrs-1)	$SS_{E(SY)}$	$MS_{E(SY)}$	
Stand Type x Year	(1)(#yrs-1)	SS_{TY}	MS_{TY}	$MS_{TY}/MS_{E(TY)}$
Site x Stand Type x Year	(2)(1)(#yrs-1)	SS_{STY}	MS_{STY}	$MS_{STY}/MS_{E(STY)}$
Error (STY)	(2)(3)(1)(#yrs-1)	$SS_{E(STY)}$	$MS_{E(STY)}$	

sample size in this study. These are calculated as follows (Zar, 1974):

$$\text{Detection Limit} = (SE) * q_{.05,df,p=2}$$

where SE is the standard error for the response variable, $q_{.05,df,p=2}$ is the critical value of the Student-Newman-Keuls multiple range test using an significance level of .05 unless othewise noted and p=2. If a response variable changes more than the detection limits, there is a greater than 50 percent chance of detecting the change; a change that is less than the detection limit has a less than 50 % chance of being detected.

WORK ELEMENTS

As stated earlier, the various work elements of this project were established to group similar tasks and analyses. Although data from several work elements are often used to test a single hypothesis, we retain the work element format in this report to allow the reader to easily refer to details presented in past annual reports. Each of the following sections presents a synopsis of the rationale for study, measures and analyses, and progress.

Element 1: AMBIENT MONITORING

The growth and development of a forest community or an individual in the community is directly related to all the environmental factors (natural and anthropogenic) which influence the physical space that the community or individual occupies. Any study which attempts to relate the development of a population to any one of these factors must also determine and screen out the effects of other independent factors. Thus, variability in plant growth, development, or phenological events within the influence of the ELF antenna system must first be related to microclimatic and other ambient variables before the effect of a single and potentially subtle factor, such as the electromagnetic fields of the ELF antenna, can be quantified (National Research Council, 1977).

Given the overall importance of ambient factors to the Upland Flora Project, the objectives of this monitoring work element are to:

1. evaluate the natural ambient differences between the control site and the test sites.

2. evaluate the natural annual ambient changes of a site over time to determine differences between pre-operational and operational time periods.

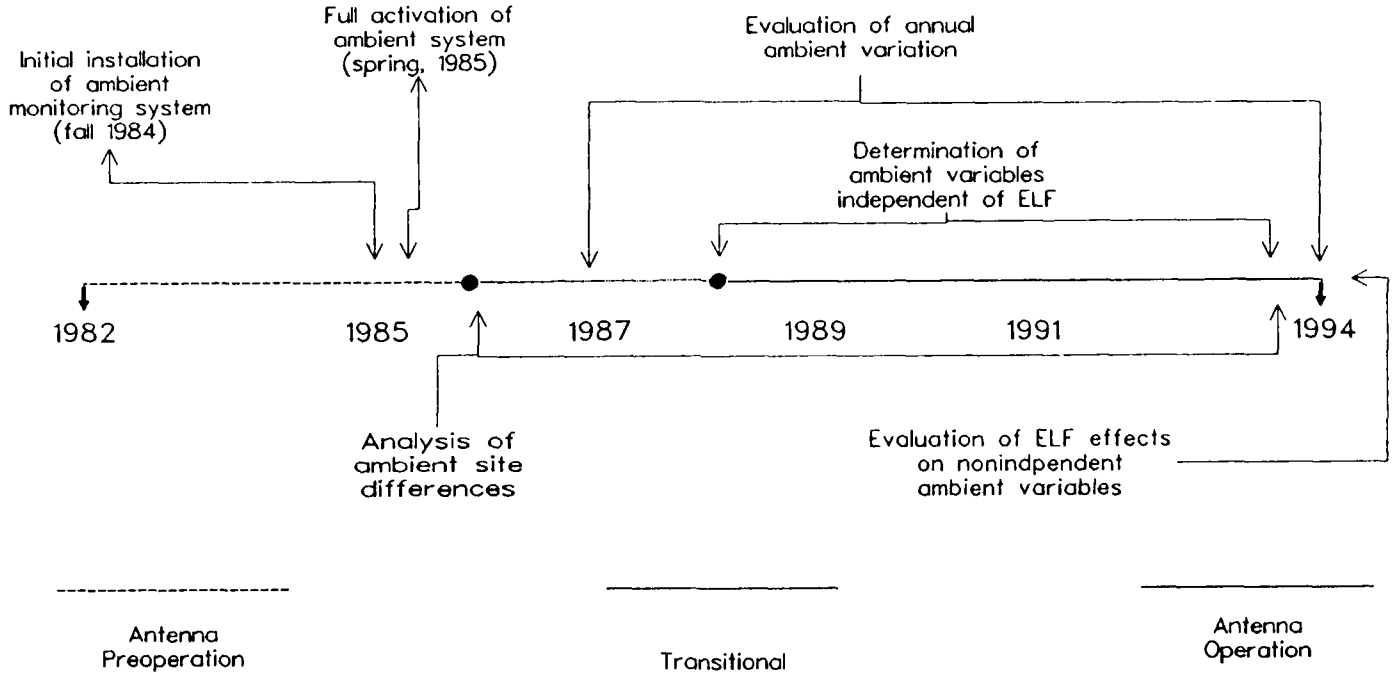
3. select ambient variables which are independent of ELF system effects. These variables will then be included in a database which can be used to (1) build models to predict community growth and development and (2) supply ambient variables as covariates for community growth and development analysis.

4. evaluate possible ELF system effects on non-independent ambient variables detected through the screening process in objective 3.

Accomplishing the first two objectives will not only document ambient differences among sites and annual changes in these conditions but also quantify ambient variables which will be potential candidates for growth and development modeling in the various study elements. An adequate database of ambient measurements will insure a proper analysis of climatic and soil relationships to other study components as discussed in the design section dealing with covariate analysis. Accomplishing the last objective will give direct measurement of any ELF system influences on such factors as solar radiation in the understory or soil nutrient status that may be affected by overstory biomass. The initiation and schedule of each phase of the objectives are presented in Figure 1.1.

Work on the Herbaceous Plant Growth and Tree Studies

Figure 1.1 Schedule and initiation of ambient monitoring objectives.



during the past four years has indicated that soil and possibly precipitation chemistry is important to the projects growth modeling efforts. Thus an increased emphasis has been placed on the collection and analysis of these variables. The ambient monitoring element is separated into two sections: climatic monitoring and nutrient monitoring.

Climatic Monitoring

Sampling and Data Collection

System Configuration

The climatic variables being measured in the study are air temperature (30cm and 2m above the ground), soil temperature and soil moisture at depths of 5 and 10 cm, global solar radiation, relative humidity, photosynthetically active radiation (PAR), and precipitation. The configuration and placement of the sensors at the study sites have been presented in Appendix B (Table 1) of the 1985 Herbaceous Plant Growth and Tree Studies Project annual report.

Because of the location of individual sensors, air temperature (2 meters above the ground) in the plantation, precipitation, relative humidity, and global solar radiation are considered to be independent of possible ecological changes caused by ELF electromagnetic fields. Air temperature at the hardwood stands, soil temperature, soil moisture, air temperature (30 cm above the ground), and PAR (30 cm above the ground) may be more sensitive to ecological changes controlled by stand characteristics.

Air temperature, soil temperature, PAR, and relative humidity are measured every 30 minutes by a Handar, Inc. ambient monitoring platform. Global solar radiation is measured every 60 minutes, soil moisture is sampled every 3 hours, and precipitation monitored continuously. A microprocessor on board the ambient system calculates three hour averages or totals for the appropriate climatic variables. These averages and totals as well as the soil moisture and global solar radiation measurements are transmitted to the GOES East satellite every three hours and relayed to Camp Springs, Virginia. The data are transferred from Camp Springs to an IBM PC at MTU nightly.

Soil moisture subsampling procedures are performed at each site in order to more accurately measure soil moisture over the entire area of each plot. Twenty cores are randomly taken from each plot at each site once a month. Moisture content for each depth (5 cm and 10 cm) is determined gravimetrically from a composite of the cores from a plot. These moisture contents are considered to

represent the average moisture content for a given plot for the day of core sampling.

Differences between the soil moisture calculated from the cores and readings from the soil moisture sensors for a given plot and day of core collection are used as an adjustment for the soil moisture readings for each plot over a monthly time interval. To eliminate any abrupt changes in soil moisture between consecutive months which would be attributed to the monthly adjustment, the weighting equation (1.1) is used to determine the actual monthly soil moisture sensor adjustments. The equation's adjustments for a given month are weighted more heavily to the month of adjustment.

Equation 1.1 Monthly adjustment for a specific plot

$$\frac{(CSM_{(M-1)}-PSM_{(M-1)})+2*(CSM_{(M)}-PSM_{(M)})+(CSM_{(M+1)}-PSM_{(M+1)})}{4}$$

CSM = Core Soil Moisture from the plot

PSM = Probe Soil Moisture from the plot

M = Month of Adjustment

M+1 = Following Month

M-1 = Previous Month

As stated in the 1986 Herbaceous Plant Cover and Tree Studies Annual Report, 1985 soil moisture measurements could not be used in any analyses. Thus the 1988 measurements were only the third full year of soil moisture measurement.

System Maintenance and Performance

The performance of the climatic monitoring system in 1988 was enhanced by the installation of lightning protection equipment at the sites through a cooperative effort between MTU and IITRI. Due to the downtime associated with this installation a few days of ambient information were lost. However this year the ambient monitoring systems were not struck by lightning and no information was lost due to lightning activity. We expect similar improvements in performance in the future as well.

Data Management

Daily averages or totals, maximums, and minimums are computed for each sensor using all 3 hour measurements (eight/day) transmitted by the platforms. If less than six transmissions are received in a day for an air temperature, relative humidity, or solar radiation sensor daily statistics for that sensor are not calculated. Due to small diurnal variability in soil temperature and soil moisture

the transmission limits for calculation of daily statistics for these sensors are four and two transmissions respectively. Weekly and monthly averages or totals are then computed from these summaries.

Weekly or seven day summaries comprise the basic climatic unit used by the tree productivity element. One summary generated from the climatic information is adjusted to correspond to the weekly measurements of tree diameter or height. For example if red pine height growth and hardwood tree diameter growth was determined for the seven days from May 9 through May 15, weekly ambient summaries are also calculated for these same seven days. This insures a consistent relationship between tree productivity measurements and climatic measurement summaries. Weekly averages are considered missing and not calculated if less than four daily averages are computed from a sensor for a given seven day period. Daily climatic information is summarized in the same manner to correspond to sampling periods in each of the other project elements.

Monthly averages and totals are the basic unit used for site and year comparisons in this study element. Weekly averages and totals corresponding to seven day periods in a month are calculated from the daily climatic averages and totals (Table 1.1). These weeks are used as repeated replicate samples for each plot during each month during the growing season (refer to analysis section).

Table 1.1. Example of weekly units.

Date	Week
May 1-7	1
May 8-14	2
May 15-21	3
May 22-30	4

Missing Data Replacement

As the result of platform and sensor downtime in the past four years, daily climatic averages or totals are estimated for days in which specific ambient observations are missing. Four hierarchical criteria and methods are used to replace the missing data. The criteria are:

1) Daily averages missing from one or two plots from a stand type of an individual site are estimated using an average of the daily summaries from the functional plots on the same stand type and site.

2) Missing daily plot averages from adjacent sites

(ground and antenna) are replaced by the stand type averages from the plantation on the adjacent site if 1) there are no significant differences between the two sites 2) there are no significant differences among plots within sites for the variable of interest. Only air temperature and precipitation have met these criteria on the ground and antenna site in the past four years.

3) Missing daily plot averages from the ground or antenna site not estimated by the methods outlined in criteria 2 are predicted using regression equations. These equations are fitted using observed data from the sensor, plot, and site combination with the missing data as the dependent variable and the observed average daily plantation observation from the other adjacent site as the independent variable.

4) Missing plot daily average air temperatures, relative humidity, and total daily precipitation at the control site are estimated from regression equations fitted to individual observed plot averages or totals and daily observations at the Crystal Falls C#200601 weather station. This weather station is located within 9 km of the control site and is operated by the Michigan Department of Natural Resources in Crystal Falls. Missing average daily soil temperatures are estimated using regression equations fitted to stand type daily averages of air temperature at the site.

Using these techniques 95% of the missing daily averages or totals can usually be replaced. Regression equations used in the data replacement along with the related regression statistics for 1985-87 have been presented in previous Herbaceous Plant Cover and Tree Studies annual reports. The 1988 equations are presented in Appendix B (Table 1-7) of this report.

Estimates of climatic measurements obtained from criteria 1-4 are used throughout the project. Coefficients of determination as well as confidence intervals for the equations are well within acceptable limits. It is felt that the missing data replacement methods give unbiased and accurate estimates of climatic measurements and thus the variables are used in the statistical analyses in the various elements.

Data Analysis

Comparisons of site and time differences of the ambient variables generally follow a split-plot in space and time experimental design (Table 1.2). Since plot locations at one site are not related to plot locations at another site, plots are nested within sites. This nesting gives a more sensitive test of main factor effects.

The design through partitioning of variability into a number of factors (site, year, stand type etc.) and associated interactions allow a number of hypotheses to be tested. For example the site factor allows testing differences in climate between sites and year factors can quantify annual changes in climate. To determine if ELF fields are affecting ambient variables at the test sites site by year, site by stand type, and site by stand type by year interactions are used to determine if the relationship of a given ambient variable changes between the stand types or control and test sites over time. These interaction terms can be used to quantify ELF field effects on climate by relating any temporal changes in climate to antenna preoperational and postoperational phases. Factors involving month indicate seasonal trends over time for climate or other ambient variables.

As mentioned in the data management section of the element, weekly summaries are the basic unit used for statistical analysis in the element. We consider these weeks as a repeated measure on a given climatic variable. Repeated measures are multiple observations on a specific experimental unit or (in the case of climatic measurements) a specific three dimensional area. Since the observations are made on the same unit they are not independent of each other. Therefore weeks are nested in plots in the design (Table 1.2).

Comparison of ambient variables among sites, years, months, etc. were made using analysis of variance tests. Differences between specific months, years, sites, etc. were made using the Student-Newmen-Keuls (SNK) multiple range test if tests with analysis of variance showed significant differences for the appropriate factor. Detection limits for each variable were also calculated using this multiple range test. All factors were tested at the 0.05 probability level for the ANOVA and SNK tests.

Analysis of ambient variables, which are only measured on a site level, year level, or on only one stand type, involved only a portion of the experimental design. Analysis of precipitation amounts involved site and year factors only because only one sensor is located at each of the plantations. Since the ground site does not have a hardwood stand type associated with it, analyses were performed for the control vs ground site and the control vs antenna site separately with stand type dropped from the analysis for the control vs ground tests.

Table 1.2. General analysis of variance of Element 1.

Source of Variation	Sum of Squares	Mean Square	F-Ratio
SI	SS(S)	MS(S)	$MS(S)/MS(E_1)$
PL w SI (Error 1)	$SS(E_1)$	$MS(E_1)$	$MS(E_1)/MS(E_2)$
WK w PL w SI (Error 2)	$SS(E_2)$	$MS(E_2)$	
YR	SS(Y)	MS(Y)	$MS(Y)/MS(E_3)$
YR x SI	SS(YS)	MS(YS)	$MS(YS)/MS(E_3)$
YR x PLwSI (Error 3)	$SS(E_3)$	$MS(E_3)$	$MS(E_3)/MS(E_4)$
YR x WKwPLwSI (Error 4)	$SS(E_4)$	$MS(E_4)$	
ST	SS(T)	MS(T)	$MS(T)/MS(E_5)$
ST x SI	SS(TS)	MS(ST)	$MS(ST)/MS(E_5)$
ST x PLwSI (Error 5)	$SS(E_5)$	$MS(E_5)$	$MS(E_5)/MS(E_6)$
ST x WKwPLwSI (Error 6)	$SS(E_6)$	$MS(E_6)$	
MO	SS(M)	MS(M)	$MS(M)/MS(E_7)$
MO x SI	SS(MS)	MS(MS)	$MS(M_5)/MS(E_7)$
MO x PLwSI (Error 7)	$SS(E_7)$	$MS(E_7)$	$MS(E_7)/MS(E_8)$
MO x WKwPLwSI (Error 8)	$SS(E_8)$	$MS(E_8)$	
YR x MO	SS(YM)	MS(YM)	$MS(YM)/MS(E_9)$
YR x MO x SL	SS(YMS)	MS(YMS)	$MS(YMS)/MS(E_9)$
YR x MO x PLwSI (Error 9)	$SS(E_9)$	$MS(E_9)$	$MS(E_9)/MS(E_{10})$
YR x MO x WKwPLwSI(Error 10)	$SS(E_{10})$	$MS(E_{10})$	
YR x ST	SS(YT)	MS(YT)	$MS(YT)/MS(E_{11})$
YR x ST x SI	SS(YTS)	MS(YTS)	$MS(YTS)/MS(E_{11})$
YR x ST x SI (Error 11)	$SS(E_{11})$	$MS(E_{11})$	$MS(E_{11})/MS(E_{12})$
YR x ST x SI x WKwPLwSI(Error 12)	$SS(E_{12})$		
ST x MO	SS(TM)	MS(TM)	$MS(TM)/MS(E_{13})$
ST x MO x SI	SS(TMS)	MS(TMS)	$MS(TMS)/MS(E_{13})$
ST x MO x PLwSI (Error 13)	$SS(E_{13})$	$MS(E_{13})$	$MS(E_{13})/MS(E_{14})$
ST x MO x WKwPLwSI (Error 14)	$SS(E_{14})$	$MS(E_{14})$	
YR x ST x MO x SI	SS(YTMS)	MS(YTMS)	$MS(YTMS)/MS(E_{15})$
YR x ST x MO x PLwSI (Error 15)	$SS(E_{15})$	$MS(E_{15})$	$MS(E_{15})/MS(E_{16})$
YR x ST x MO x WKwPLwSI (Error 16)		$SS(E_{16})$	$MS(E_{16})$

Site = SI, S Within=w
Stand Type = ST, T By=x
Year = YR, Y
Month = MO, M
Plot = PL

Progress

This year concludes the fourth full year of data collection by the ambient monitoring system. It was the second year of low level operation of the ELF antenna. Thus comparisons of sites, years, and site by year interactions are presented and related to possible detection of ELF effects on climatic variables. The power or detection limits associated with these tests will also be presented for each climatic variable.

Air Temperature (2m above the ground)

Air temperature has a substantial influence on plant physiological processes such as photosynthesis, cell division, and elongation, chlorophyll synthesis, and enzymatic activity (Kramer and Kozlowski 1979). For any individual species given a specific period during the growing season, optimal net photosynthesis is associated with a specific range of temperatures (Waring and Schlesinger 1985). Thus differences in air temperature between the control and test sites or among study years could have significant effects on vegetation growth and development.

Site Comparisons: Monthly average air temperature for the three sites for 1988 are presented in Appendix B (Table 8). As shown in Figures 1.2-1.4 air temperature at the control site is consistently warmer than at the test sites regardless which stand type is being compared. Average temperature during the growing season over the four year study period was 0.7^{o}C and 0.8^{o}C warmer at the control site plantation than at the antenna and ground plantations respectively (Table 1.3). Average temperature at the control hardwood stand was 0.8^{o}C warmer than at the antenna hardwood stand. ANOVA tests show significant differences between the control and ground sites ($p=0.004$) as well as the control and antenna sites ($p=0.001$).

Annual Comparisons: Air temperatures in 1987 and 1988 were warmer than in all preceding years for all sites and stand types (Table 1.3). ANOVA tests show significant differences among years ($p<.001$) for both the control antenna and control ground comparisons. Multiple range tests ($p=0.05$) rank annual air temperature for both comparisons as follows: 1988=1987>1986>1985. In 1988 air temperature was cooler in April and October but warmer in May through September for all sites than in previous years (Figures 1.2-1.4).

Figure 1.2.

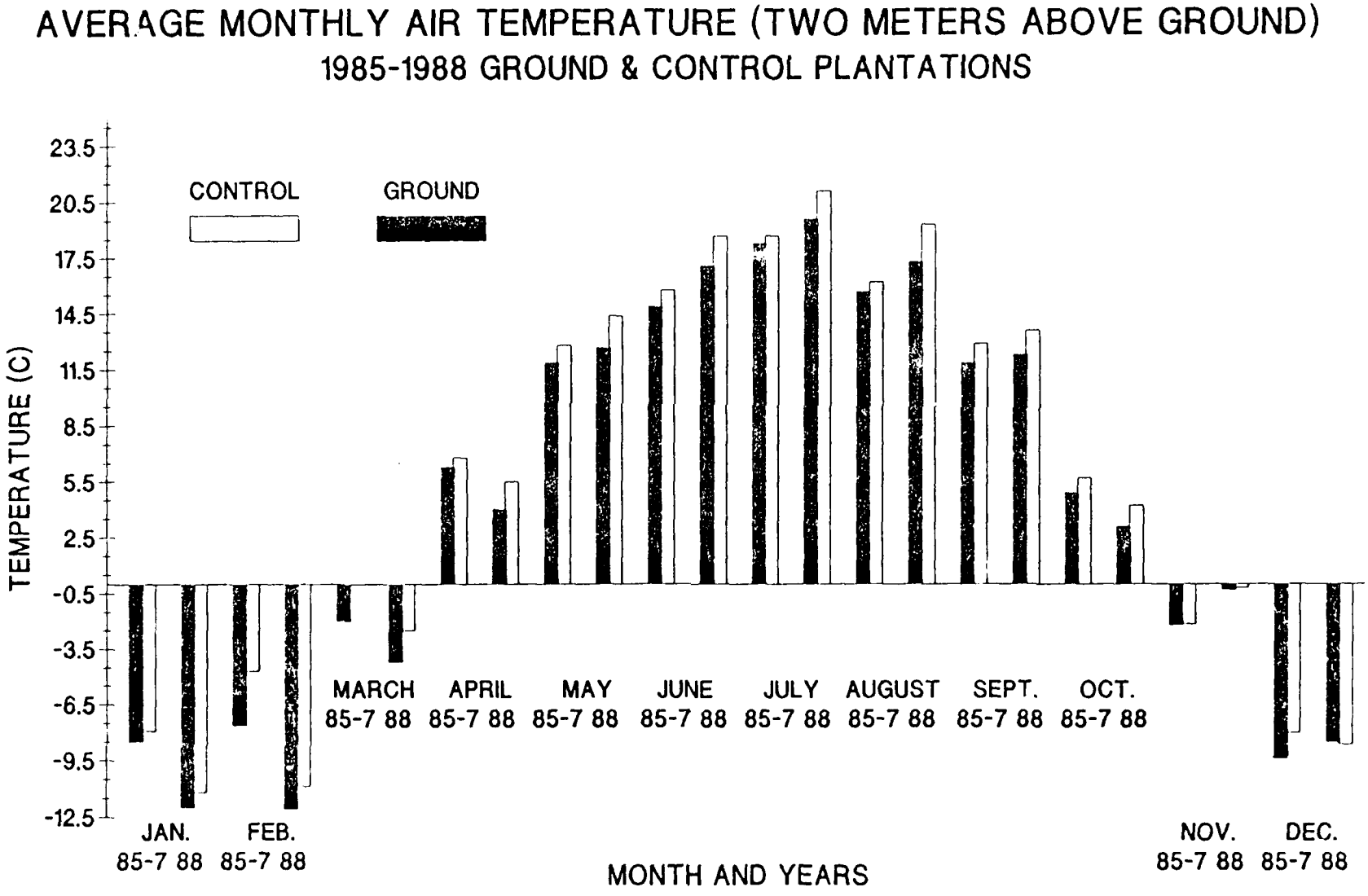

AVERAGE MONTHLY AIR TEMPERATURE (TWO METERS ABOVE GROUND)
1985-1988 GROUND & CONTROL PLANTATIONS
CONTROL
GROUND
TEMPERATURE (C)
23.5
20.5
17.5
14.5
11.5
8.5
5.5
2.5
-0.5
-3.5
-6.5
-9.5
-12.5
JAN. 85-7 88
FEB. 85-7 88
MARCH 85-7 88
APRIL 85-7 88
MAY 85-7 88
JUNE 85-7 88
JULY 85-7 88
AUGUST 85-7 88
SEPT. 85-7 88
OCT. 85-7 88
NOV. 85-7 88
DEC. 85-7 88
MONTH AND YEARS

Figure 1.3.

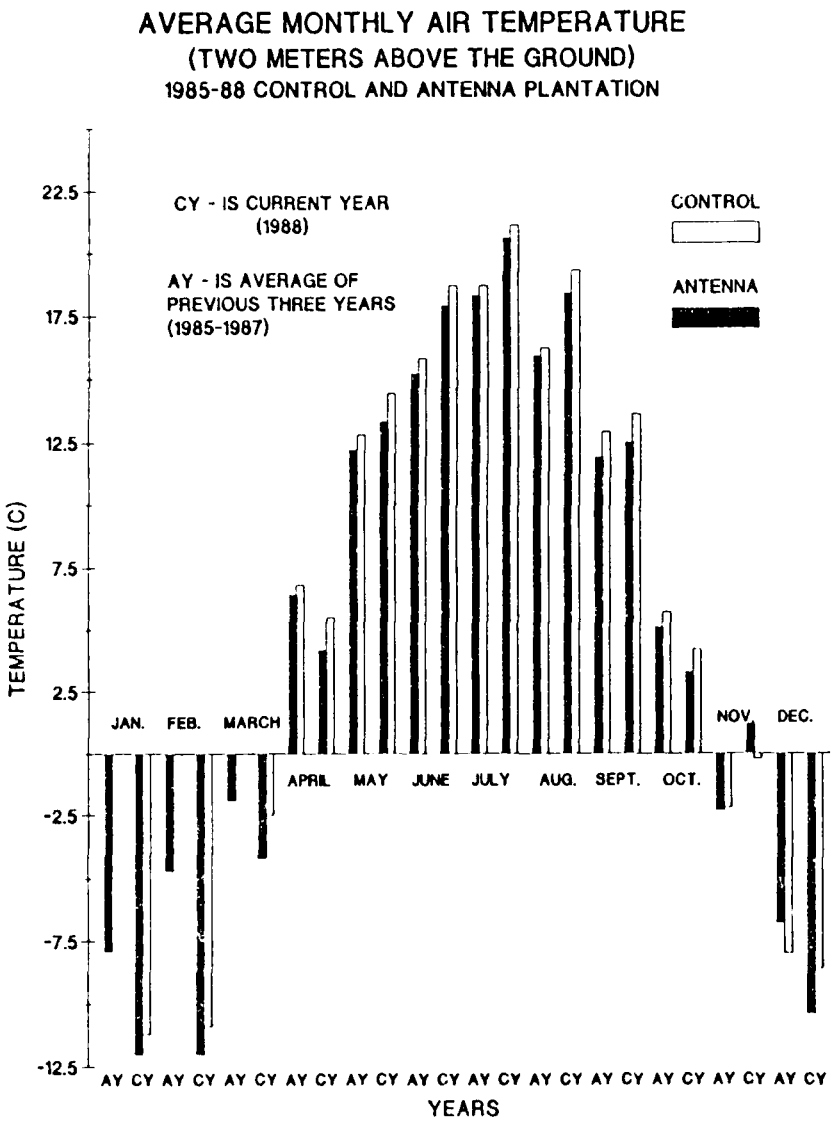


Figure 1.4.

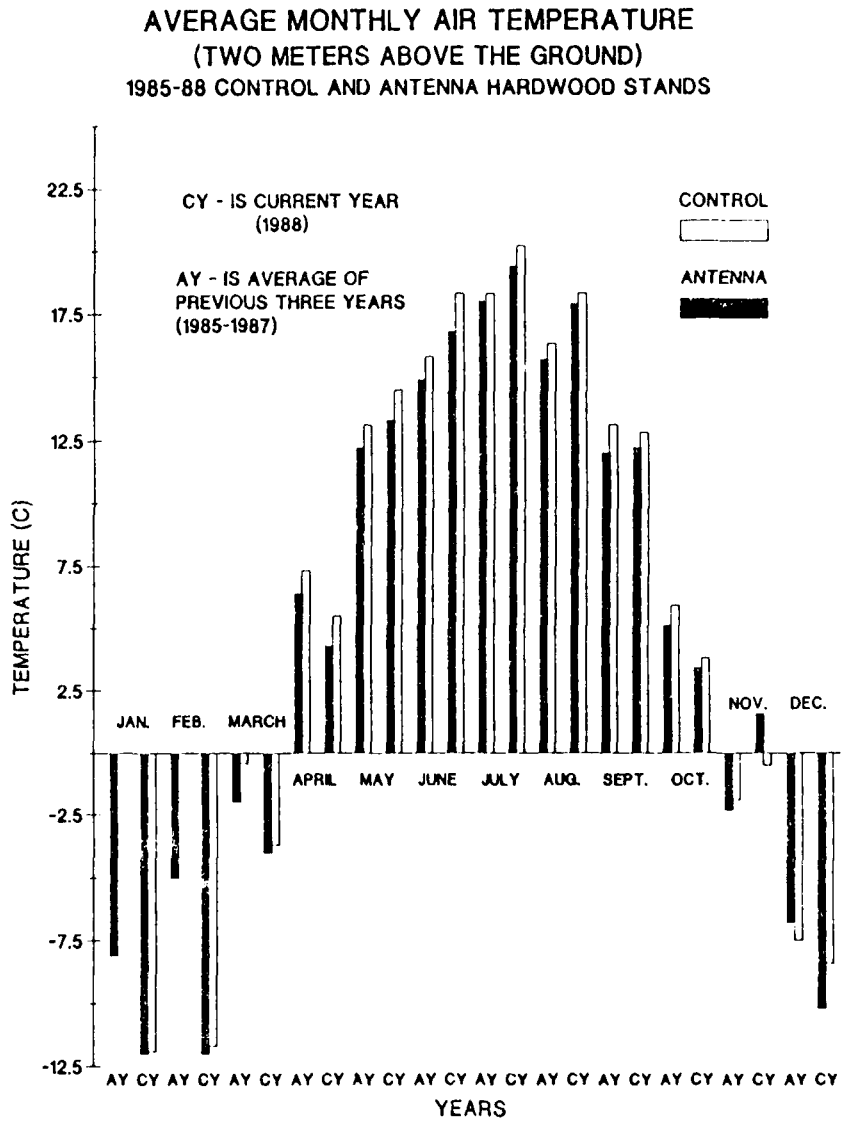


Table 1.3 Comparisons of air temperature (2 m above ground) during the 1985-1988 growing seasons.

	Stand Type									
	Plantation					Hardwood				
	1985	1986	1987	1988	$\bar{X}$	1985	1986	1987	1988	$\bar{X}$
Control	11.9	12.5	13.6	13.8	13.0	12.3	12.9	13.5	13.3	13.0
Antenna	11.5	12.1	12.9	12.9	12.3	11.4	12.0	12.7	12.5	12.2
Ground	11.4	12.0	12.7	12.3	12.1					
Control-Antenna	.4	.4	.7	.9	.7	.9	.9	.8	.8	.8
Control-Ground	.5	.5	.9	1.5	.9					

Average Air Temperature (Site Comparison)

Control	Antenna
12.9 a[1/]	12.1 b

Control	Ground
12.7 a	12.0 b

Average Air Temperature (Year)

Control & Antenna				Control & Ground			
1985	1986	1987	1988	1985	1986	1987	1988
11.8 a	12.4 b	13.2 c	13.1 c	11.7 a	12.3 b	13.2 c	13.1 c

[1/] Sites or years comparisons with the same letters for specific site combinations are not significantly different ($p=0.05$).

All values expressed in ^{o}C

Site by Year Comparisons: Previous analyses have indicated no significant site by year interactions and thus to date we have concluded that the relationship of air temperature between the control and test sites have remained stable. Although this years ANOVA tests again indicated no significant differences in site by year interactions for the control antenna comparisons (p=.594), site by year interactions were significant for the control vs ground comparisons (p=.035). Differences between average air temperatures during the growing season at the control compared to the ground increased from a low of 0.5°C in 1985 to 1.5°C in 1988, while differences between average air temperature at the control and antenna plantation over the same time period only increased by 0.5°C. Although differences in air temperature between the control and antenna site increased in the plantation, differences have decreased or remained the same in the hardwood stand types. The changes in the relationship between the air temperatures at the control and test sites may be a result of the changes in the structural characteristics of the plantations (height, leaf area, density) at these sites. However, one would also expect that the differences in stand characteristics between the hardwood and plantation would also significantly effect average daily air temperatures at these two stand types. To date no significant differences (p=.422) between average daily air temperatures in the two stand types during the growing seasons have been detected.

Detection Limits and Summary: Detection limits associated with each of the factors (Table 1.4) were well

Table 1.4. Detection limits (p=.05) associated with year and site factors for air temperature (2 m above ground) during 1985-1988.

Factor	Detection Limit °C	% Mean
Site (Control vs. Ground)		
Site	.59	4.66
Year	.30	2.37
Site x Year	.42	3.36
Site (Control vs. Antenna)		
Site	.28	2.24
Year	.13	1.02
Site x Year	.19	1.46
Site x Stand Type	.14	1.09
Site x Stand Type x Year	.32	2.51

within acceptable limits. The detection limits associated with the site factors are larger than detection limits associated with year factors.

This year as in previous year's analyses we found significant differences in air temperatures between sites and among years. However this year we also found significant site by year interactions for the control vs ground comparison. These differences reflect a greater increase in air temperature during the four year study period at the control plantation compared to the ground plantation. The same trend is evident when comparing the control and antenna plantations but not the hardwood stand type. Although differences between the average air temperatures at the control and antenna plantations increase by $.5^{o}C$ over the four year period, no significant site by year, site by year by stand type interactions were found.

If changes in local air temperature patterns have caused the changes in the relationship of air temperatures between the control and test plantations, one would expect these differences to be present in comparisons of the hardwood type at the antenna as well. This does not appear to have happened since the differences in air temperature between the hardwood stand have decreased not increased.

Another factor which could explain the increase in temperature differences between the sites is the different growth rates of the vegetation in the plantations during the study period. Red pine height growth has been greater at the control than at the antenna site and greater at the antenna than at the ground site. Differences in red pine height among the sites would also indicate differences in leaf area and stand structure among the sites. Stand structure, leaf area, and a number of other stand characteristics can effect long and short wave absorption and emission, vapor pressure gradients, and wind turbulence. Thus changes in the relationship of air temperatures among the plantations may be related to changes of the stand characteristics among the plantations. If such subtle changes in stand characteristics could affect air temperature, one would also expect that drastic differences in stand characteristics between the hardwood and plantation stand types would also affect average daily temperatures as well. However, to date we have found no significant differences in average daily air temperatures between the two stand types at either site.

ELF antenna operation could affect air temperatures by affecting the productivity of the vegetation and thus stand characteristics which influence air temperature. Until differences in productivity due to the ELF fields are documented we will not be able to conclude that ELF fields have affected air temperature in this manner.

Soil Temperature

Soil temperature like air temperature has a direct influence on plant physiological process such as cell division and elongation. However soil temperature also indirectly influences plant growth by affecting permeability of roots and thus water uptake (Kramer 1983), biological decomposition and availability of nutrients (Brady 1974). Climatic conditions or stand characteristics such as insolation, air temperature, and precipitation as well as soil characteristics are the main factors controlling soil temperatures. Thus possible changes in vegetation or soil properties (organic matter content etc.) due to ELF antenna operation could have a major effect on soil temperature. These effects would appear to be more dramatic in the hardwood stands where microclimate is influenced to greater degree by vegetation than it is in the younger plantation stands.

Soil Temperature (depth of 5cm)

Site comparisons: Differences between average daily soil temperatures (5cm) during the growing season at the control and test plantations were less than .5^{o}C during each year of the study period (Table 1.5). Although soil temperatures during the growing season were not consistently warmer at the control plantation than at the test plantations, soil temperatures were consistently warmer at control hardwood stand than at the antenna hardwood stand (Table 1.5, Figures 1.5-1.7).

ANOVA tests showed no significant differences in soil temperature (5cm) between the control and ground site ($p=0.219$) or the control and antenna sites ($p=0.368$). Differences between sites were more apparent when soil temperatures were compared for each individual month of the growing season. Except in 1988 soil temperature (5cm) warmed in the spring months (April, June, and July) and cooled in the fall (September and August) more rapidly at the test plantations sites than at the control plantation sites (Figure 1.5-1.7). Although not as apparent as in the plantation stand type, this phenomenon occurs in the hardwood stands as well (ie. differences between control and antenna sites are greatest in August and September and least in April and May, Figure 1.7).

Site by stand type interactions were significantly different ($p<.001$) for the control vs antenna comparison. Multiple range tests ranked the soil temperatures (5cm) for each site and stand type in the following order: antenna plantation=control plantation>control hardwoods>antenna hardwoods. Although the multiple range tests showed no significant differences between the control and antenna plantations, the control hardwood stand was shown to be significantly warmer than the antenna hardwood stand.

Table 1.5 Comparisons of average daily soil temperature °C (5cm) during the 1985-1988 growing seasons.

Stand Type

	Plantation					Hardwood				
	1985	1986	1987	1988	$\bar{X}$	1985	1986	1987	1988	$\bar{X}$
Control	12.5	13.2	13.6	13.7	13.3	10.9	11.7	12.3	11.6	11.6
Antenna	12.9	13.5	13.7	13.5	13.4	10.1	11.2	11.8	11.2	11.1
Ground	12.5	13.3	13.5	13.2	13.1					
Control-Antenna	-.4	.0	-.1	.2	-.1	.8	.5	.5	.4	.5
Control-Ground	.0	.2	.1	.5	.2					

Average Soil Temperature (5cm)
(Site Comparison)

Control	Antenna
12.4 a[1/]	12.2 a

Control	Ground
13.3 a	13.1 a

Average Soil Temperature (5 cm)
(Year Comparison)

Control & Antenna				Control & Ground			
1985	1986	1987	1988	1985	1986	1987	1988
11.6 a	12.4 b	12.8 c	12.5 b	12.5 a	13.4 b	13.6 b	13.5 b

[1/] Site or year comparisons with the same letters for specific site combinations are not significantly different (p=0.05).

All values expressed in °C

Figure 1.5.

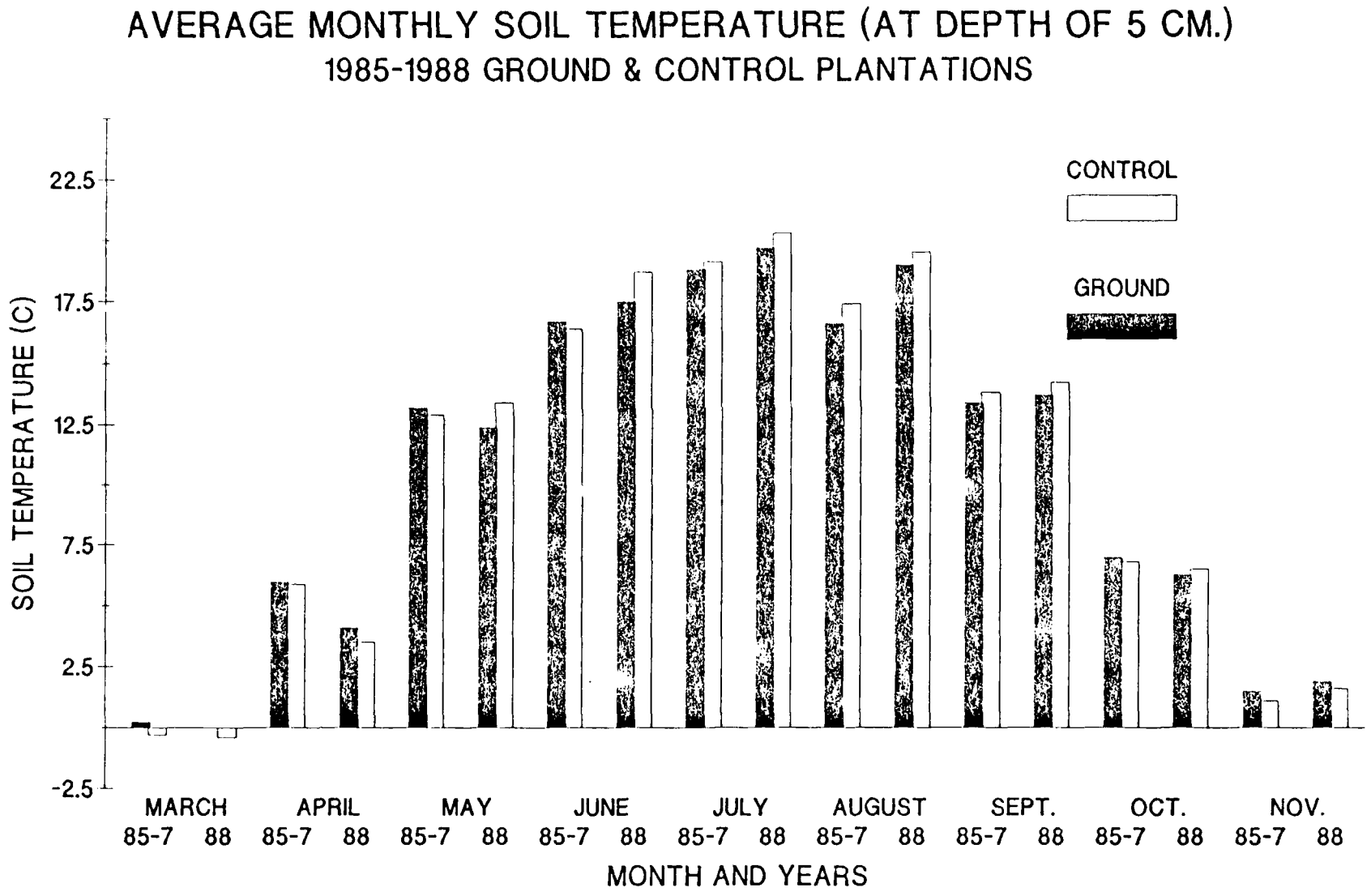

AVERAGE MONTHLY SOIL TEMPERATURE (AT DEPTH OF 5 CM.)
1985-1988 GROUND & CONTROL PLANTATIONS
CONTROL
GROUND
SOIL TEMPERATURE (C)
22.5
17.5
12.5
7.5
2.5
-2.5
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
NOV.
85-7 88
MONTH AND YEARS

Figure 1.6.

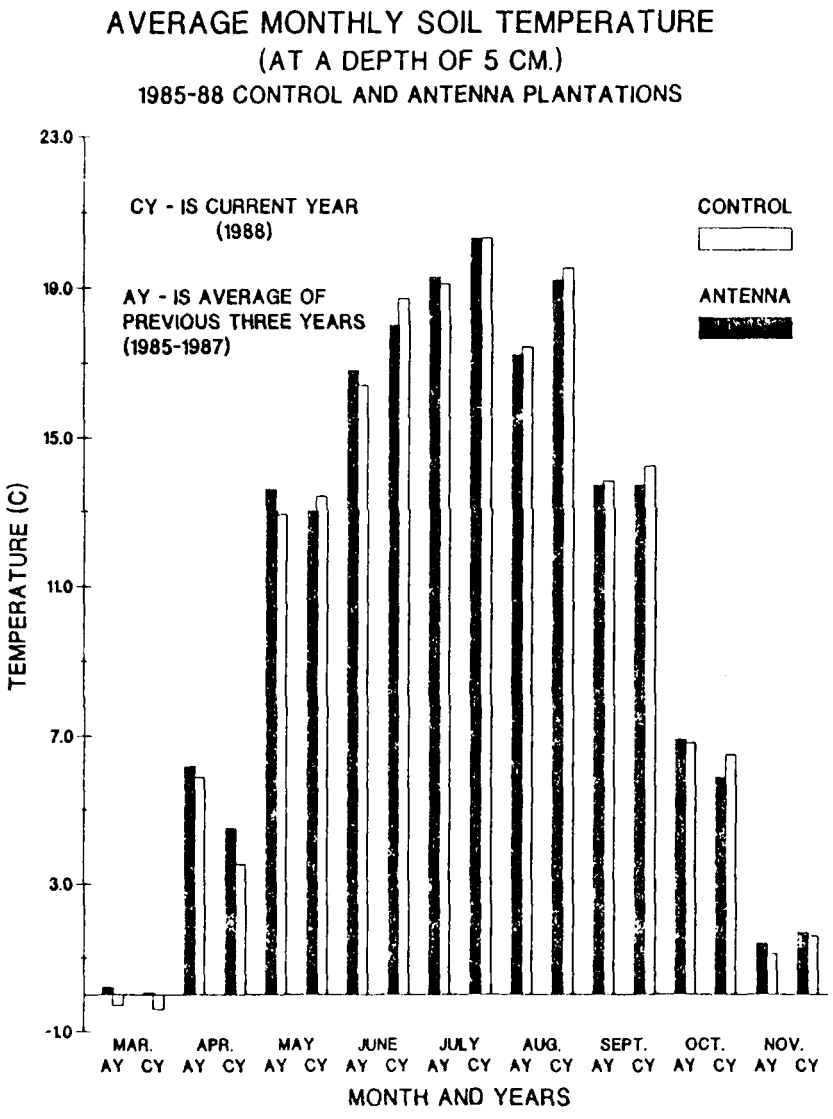
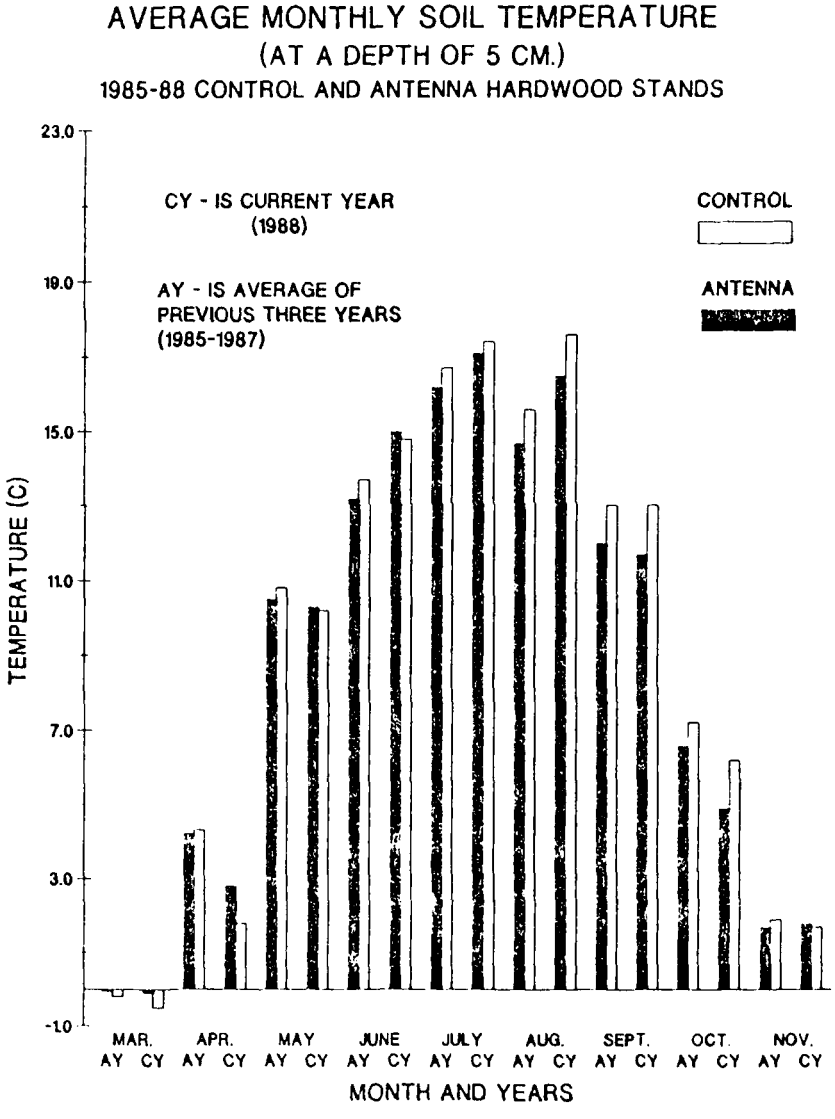


Figure 1.7.



Differences in the relationships between sites for a given stand type appears to be related to the physical factors influencing soil temperatures at each site and stand type combination. In the plantations where insolation is much lower than in the hardwood stands, solar radiation is a critical factor influencing soil temperatures at 5cm. Assuming that the amount of solar radiation received at each site is equal, soils warm faster in the antenna plantation than at the control plantation due to the lower water holding capacity at the antenna compared to control site. However later in the year differences in soil temperatures between sites are minimized by the higher air temperatures at the control site. As a result of these site and stand type characteristics soil temperatures are not significantly different between the control and antenna plantations.

In the hardwood stands where solar radiation does not affect soil temperatures to the same degree it does in the plantations, air temperature is a more critical factor influencing soil temperatures. As a result of warmer air temperatures at the control compared to the antenna site, soils at the control hardwood stand are warmer than at the antenna hardwoods. Although soil temperature relationships among the site and stand types vary, ANOVA tests indicated no significant site by stand type by year interactions ($p=.675$).

Annual Comparisons: Average soil temperature at 5cm was significantly warmer in 1986-1988 than in 1985 for all site comparisons. Only the control and antenna site comparison produced significant differences between 1986 or 1988 compared to 1987. For all sites and stand types average soil temperatures (5cm) were higher in 1987 than 1986 and higher in 1986 than 1985 (Table 1.5).

Site by Year Comparisons: Site and year interactions were not significant for the control vs. antenna site comparison ($p=0.919$) or the control vs. ground site comparison ($p=0.394$). This suggests that average soil temperature (5cm) for a given site and year can be adequately explained by site and year factors alone. Site by stand type by year interactions were also not significantly different ($p=.675$). Thus changes in soil temperature at sites from one year to the next have not been effected by different stand characteristics of the two stand types.

Detection Limits and Summary: Except for site by stand type by year interactions, detection limits associated with soil temperature (5cm) were below 5.0% of the mean (Table 1.6). The detection limit for this factor (site by stand

Table 1.6. Detection limits (p=.05) associated with year and site factors (1985-1988) for soil temperature (5cm).

Factor	Detection Limit °C	% Mean
Site (Control vs Ground)		
Site	.27	2.05
Year	.36	2.73
Site x Year	.49	3.72
Site (Control vs Antenna)		
Site	.57	4.33
Year	.23	1.75
Site x Year	.33	2.50
Site x Stand Type	.53	4.02
Site x Stand Type x Year	.82	6.22

type by year) was 6.22% of the mean.

This year's comparisons indicate that the present level of ELF exposure has not affected soil temperature at depths of 5cm. This conclusion is based on: 1) differences between sites were not significant at p=.05, 2) although differences between years were significant, site by year interactions were not different, and 3) although site by stand type interactions were different, these differences have remained stable during the four year study period. These factors suggest that soil temperature relationships between the control and test sites as well as two stand types have remained stable over the study period and ELF antenna operation has not changed these relationships.

Soil Temperature (depth 10cm)

Site Comparisons: Average soil temperature (10cm) at the control site were within 0.4°C and 0.6°C of the average soil temperatures (10cm) at the test site plantations and hardwood stand respectively throughout the study period (Table 1.7). Comparisons of the sites using ANOVA tests showed no significant differences between the control and antenna sites (p=.358) or the control and ground sites (p=.359).

Annual Comparisons: ANOVA tests indicated significant differences among years for all site comparisons (control vs ground p<.001 and control vs antenna p<.001). Multiple range tests (p=.05) ranked the annual soil temperature (10

Table 1.7 Comparisons of average daily soil temperature °C (10cm) during the 1985-1988 growing seasons.

	Stand Type									
	Plantation					Hardwood				
	1985	1986	1987	1988	$\bar{X}$	1985	1986	1987	1988	$\bar{X}$
Control	12.4	13.3	13.6	13.2	13.1	10.8	11.5	11.5	11.3	11.3
Antenna	12.6	13.4	13.6	13.2	13.2	10.2	10.9	11.7	11.0	11.0
Ground	12.2	13.0	13.2	13.3	12.9					
Control-Antenna	-.2	-.1	.0	.0	-.1	.6	.6	-.2	.3	.3
Control-Ground	.2	.3	.4	-.1	.2					

Average Soil Temperature (10cm) (Site Comparison)

Control	Antenna
12.2 a[1/]	12.1 a

Control	Ground
13.1 a	12.9 a

Average Soil Temperature (5 cm) (Year Comparison)

Control & Antenna				Control & Ground			
1985	1986	1987	1988	1985	1986	1987	1988
11.5 a	12.3 b	12.6 c	12.2 b	12.3 a	13.1 b	13.4 b	13.3 bc

[1/] Sites or years comparisons with the same letters for specific site combinations are not significantly different (p=0.05).

All values expressed in °C

Figure 1.8.

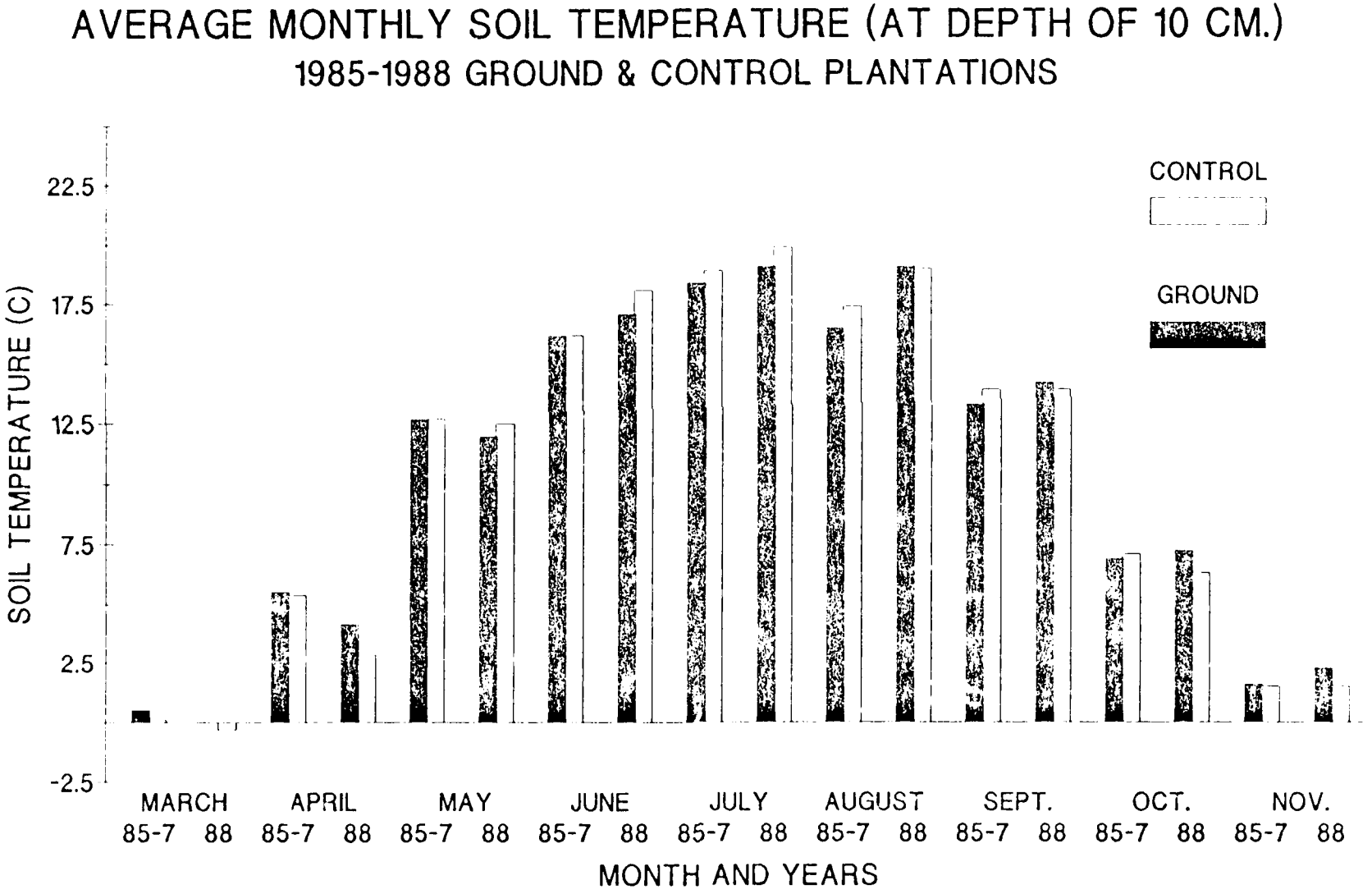

AVERAGE MONTHLY SOIL TEMPERATURE (AT DEPTH OF 10 CM.)
1985-1988 GROUND & CONTROL PLANTATIONS
CONTROL
GROUND
SOIL TEMPERATURE (C)
22.5
17.5
12.5
7.5
2.5
-2.5
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
NOV.
85-7 88
MONTH AND YEARS

Figure 1.9.

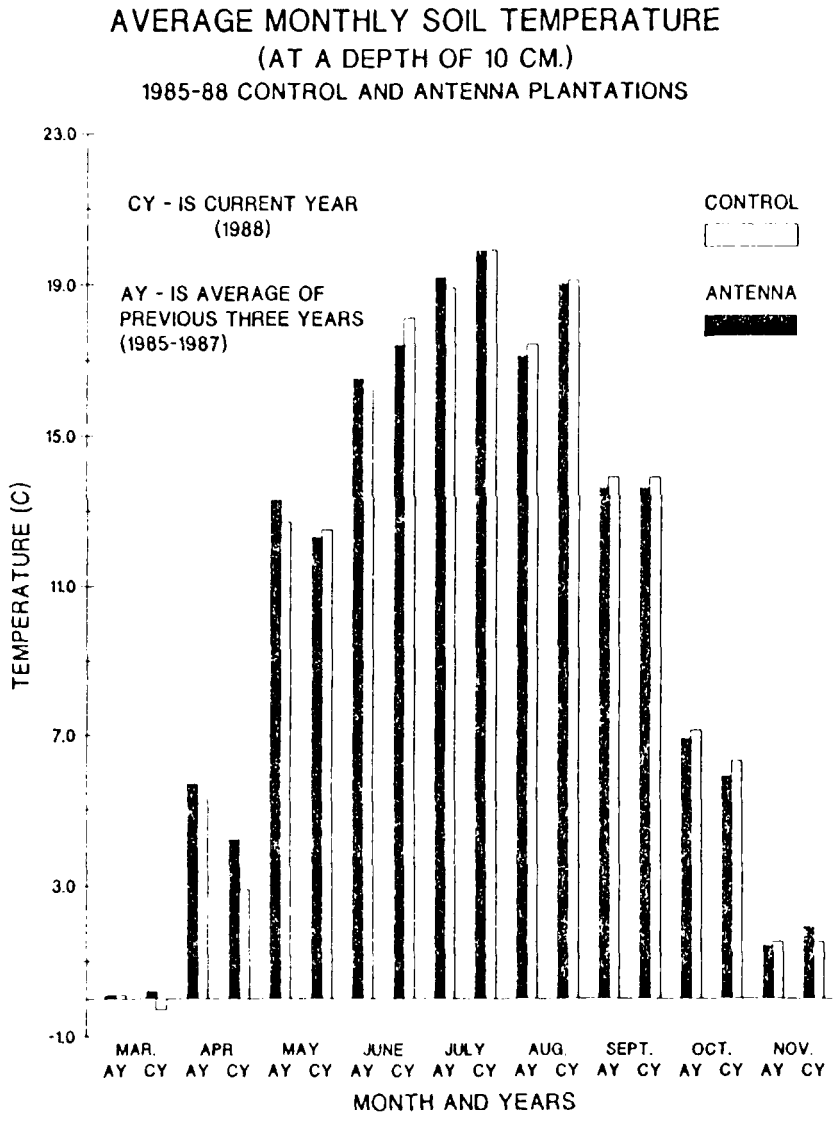
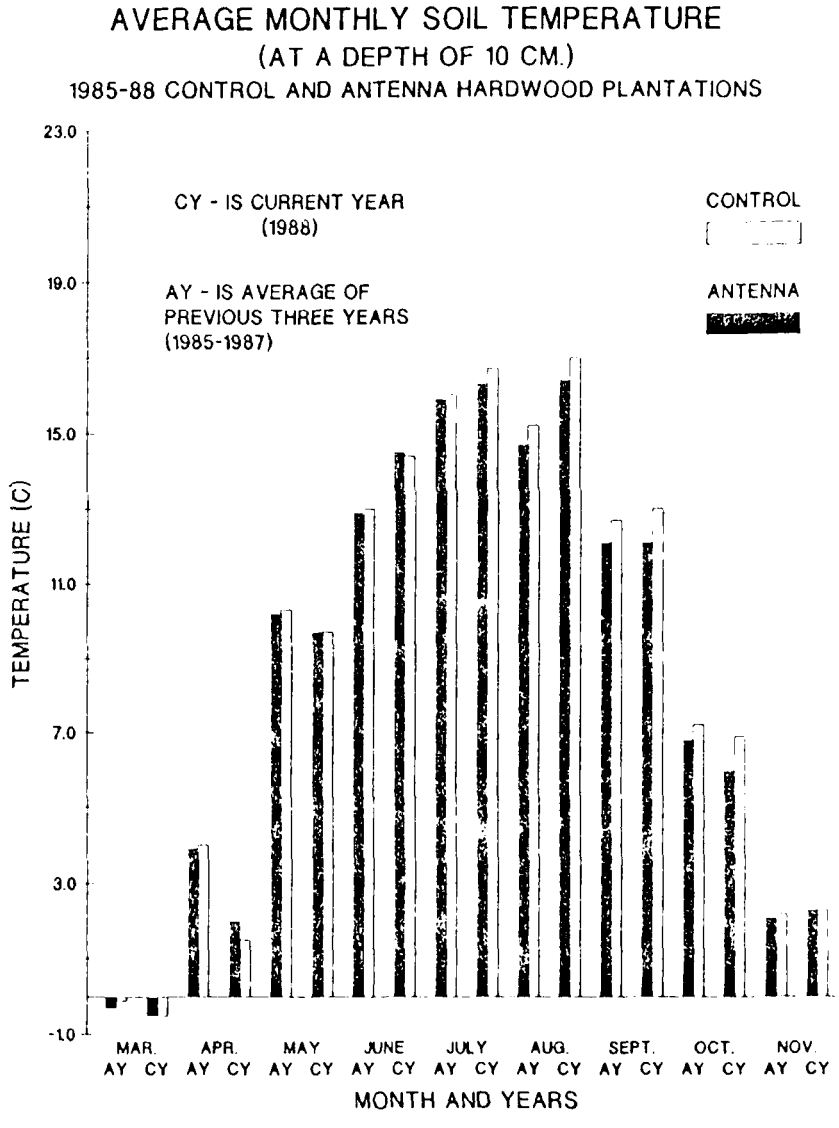


Figure 1.10



cm) for the control vs antenna comparison in the following order: 1987>1988=1986>1985 (Table 1.7). Multiple range tests for the control vs ground analysis had similar results except 1987 was not significantly warmer than 1988.

Site by Year Comparisons: No significant differences were found for site by year interactions for the control vs antenna (p=0.553) or control vs ground comparisons (p=0.318). However, differences between sites during the study period were more apparent when stand types are considered separately. Table 1.7 shows that average soil temperature (10cm) was .6°C warmer at the control hardwood stand than at the antenna hardwood stand type during 1985 and 1986, .2°C cooler in 1987, and then .3°C warmer in 1988. This variation in part appears to be related to the annual trends in temperature at the sites. Difference between the sites were greatest during the coolest years (1985 and 1986) and least during the warmest year of the study (1987). These trends were not as apparent for comparisons of the control and antenna plantations. Furthermore no significant differences were found for the site by stand type by year interactions (p=.186). Thus if these trends actually exist they represent temperature variations that are less than the detection limits of our design.

Table 1.8 Detection limits (p=.05) associated with year and site factors (1985-1988) for soil temperature (10 cm).

Factor	Detection Limit °C	% Mean
Site (Control vs Ground)		
Site	.39	3.00
Year	.24	1.85
Site x Year	.34	2.61
Site (Control vs Antenna)		
Site	.27	2.24
Year	.26	2.17
Site x Year	.37	3.09
Site x Stand Type	.59	4.91
Site x Stand Type x Year	.58	4.82

Detection Limits and Summary: Detection limits for all

factors were below 5.0% of the mean (Table 1.8). The factors which have the lowest detection limits were site, year, and site by year interactions.

No significant differences were found for site and site by year interactions but years were found to be significantly different at p=.05. Site by stand type by year interactions were also not significantly different at p=.05. To date we have found no evidence to conclude that soil temperature at 10cm is affected by the ELF antenna at this stage of operation.

Soil Moisture

The amount and availability of water is a key factor in determining forest site productivity. The importance of water to plant growth should not be underestimated since almost all plant processes are influenced by the supply of water (Kramer 1983). Water in the soil is the primary media for transportation of nutrients within plants and is a reagent in photosynthesis. Apical and radial growth of trees have been shown to be highly correlated to soil water supplies (Zahner 1968).

Soil moisture tension was analyzed to more fully investigate moisture relationships among the sites. Although moisture content gives a valuable measurement of the amount of water contained in the soil, it does not reflect to what degree plants can utilize this water. The tension at which water is held determines the biologically available water.

Given a specific moisture content, the availability of water can vary depending on soil characteristics. Thus tension may give a more sensitive estimate of site and year comparisons among the study sites. Tension values were estimated from equations relating soil moisture content at each plot to soil moisture tension (Appendix C 1987 Herbaceous Plant Cover and Tree Studies Annual Report). These equations were then applied to daily average soil moisture content at each depth at each plot.

Last year we expressed concerns that the frequency distributions of soil tensions were not normal and thus they did not meet the assumptions for ANOVA testing. This year statistical tests were performed to quantify these distributions. Histograms of both soil moisture at 10cm and soil tension at 10cm for the years 1986-1988 at the ground site are presented in Figures 1.11 and 1.12 as an example of the types of distributions. These figures show the differences in the distributions of these two types of soil moisture measurements. Three measures of normality for tension are presented in Table 1.9. From these measurements we concluded that the distribution of soil tension was not normal and applied a number of transformations to the data to normalize the distributions. A natural logarithm inverse transformation gave the best results as measured by

Figure 1.11.

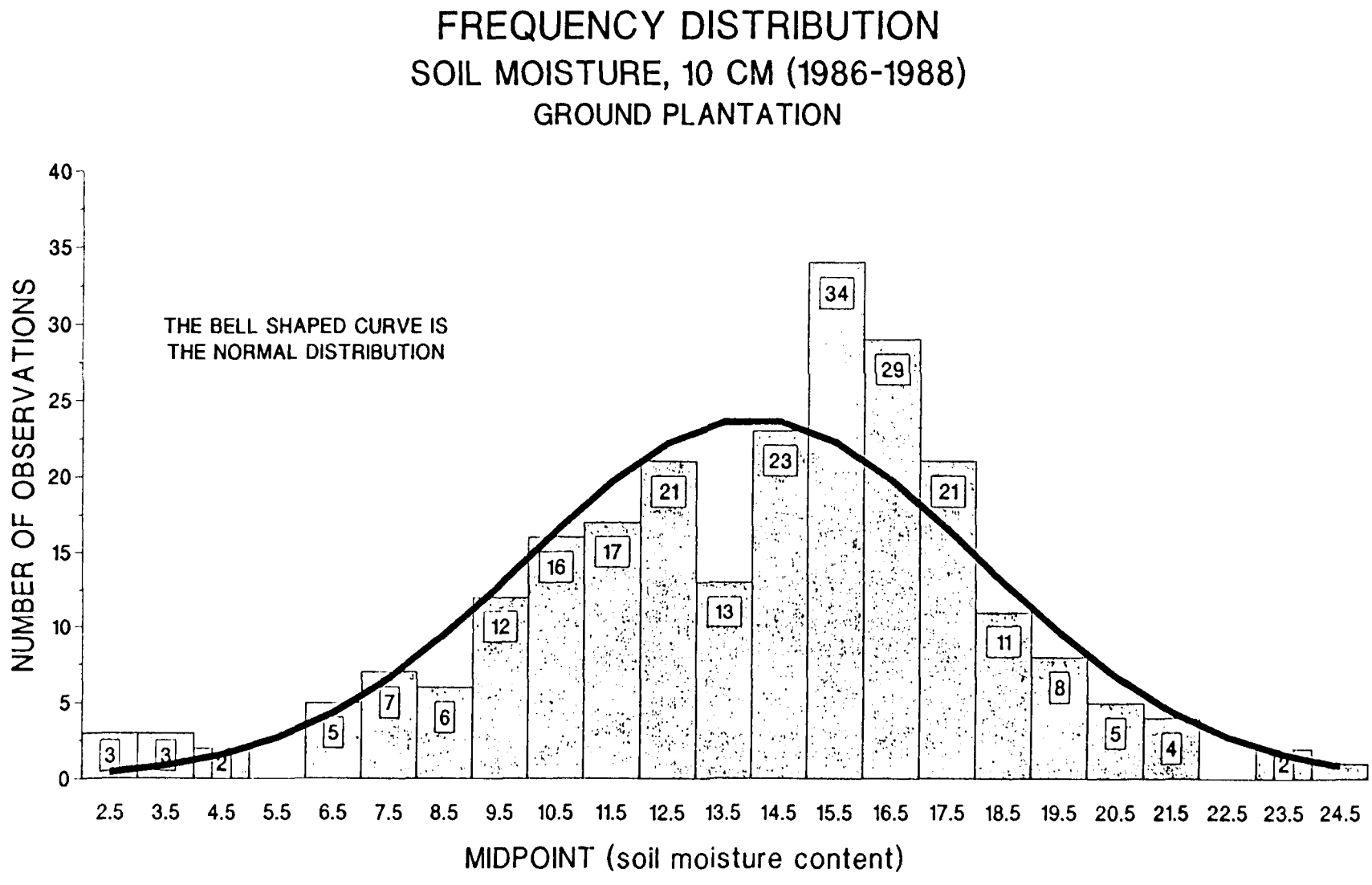
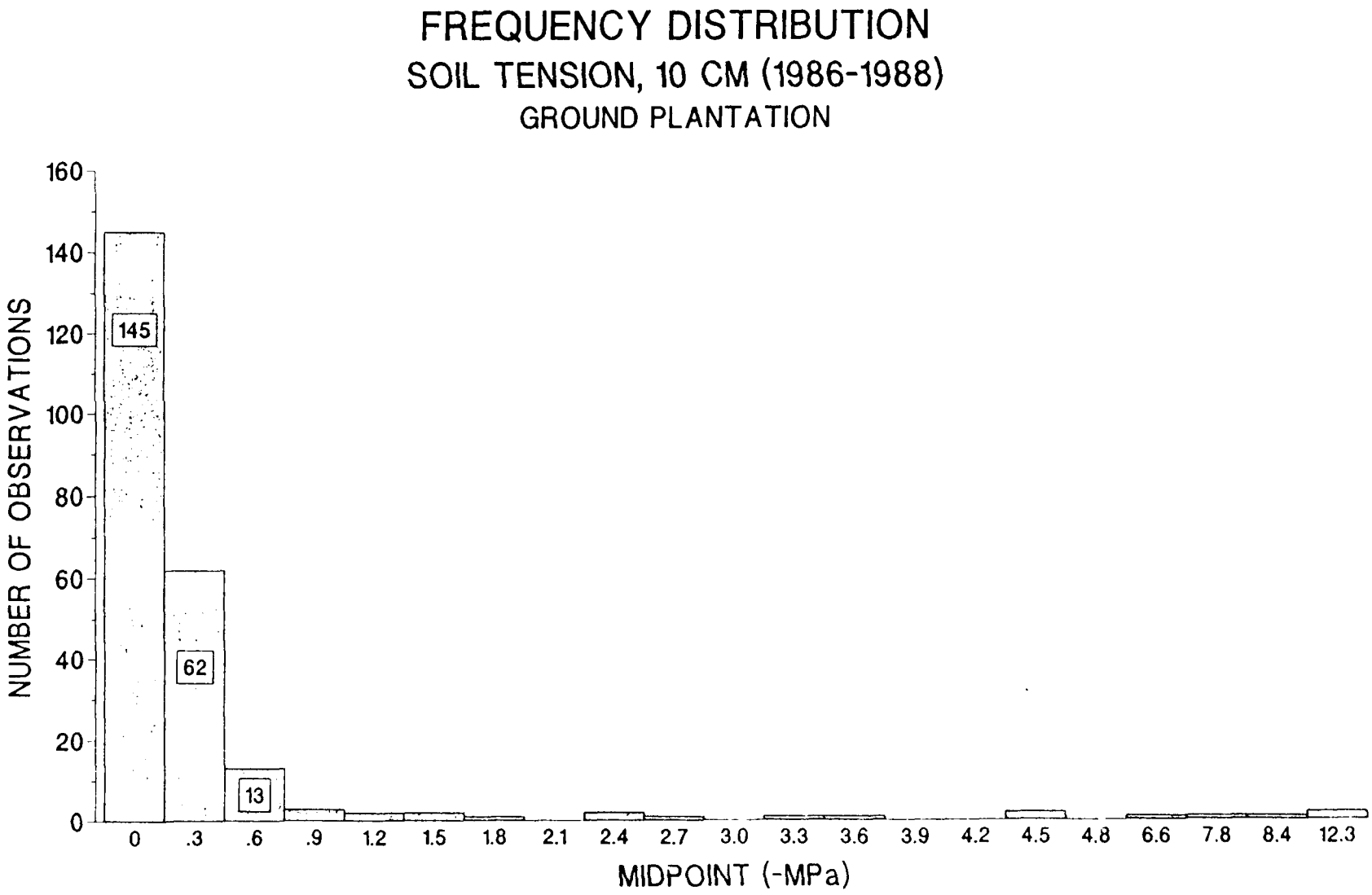

FREQUENCY DISTRIBUTION
SOIL MOISTURE, 10 CM (1986-1988)
GROUND PLANTATION
THE BELL SHAPED CURVE IS
THE NORMAL DISTRIBUTION
NUMBER OF OBSERVATIONS
0
5
10
15
20
25
30
35
40
3
3
2
5
7
6
12
16
17
21
13
23
34
29
21
11
8
5
4
2
2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5 15.5 16.5 17.5 18.5 19.5 20.5 21.5 22.5 23.5 24.5
MIDPOINT (soil moisture content)

Figure 1.12.


FREQUENCY DISTRIBUTION
SOIL TENSION, 10 CM (1986-1988)
GROUND PLANTATION
NUMBER OF OBSERVATIONS
160
140
120
100
80
60
40
20
0
145
62
13
0
.3
.6
.9
1.2
1.5
1.8
2.1
2.4
2.7
3.0
3.3
3.6
3.9
4.2
4.5
4.8
6.6
7.8
8.4
12.3
MIDPOINT (-MPa)

skewness, kurtosis, and the Kolmogorov-Smirnov cumulative distribution test (Table 1.9). Figure 1.13 shows the distribution of tension after tran formation. The Kolomogorov-Smirnov test still indicated that this distribution was not normal, however kurtosis, skewness, and the K-S test statistic were dramatically reduced.

Although distributions of natural logarithm inverse of soil tension does not appear to be normal, ANOVA tests are rather robust concerning assumptions of normality. Thus all ANOVA and multiple range tests for tension were performed on the transformed observations. Detection limits were computed for the transformed data and presented in the following discussions. Although all tests were done on the transformed data, site, year, and stand type means are presented in the form of the untransformed soil tension. Next year we will investigate the use of nonparametric tests for determining differences for the main factors of the design.

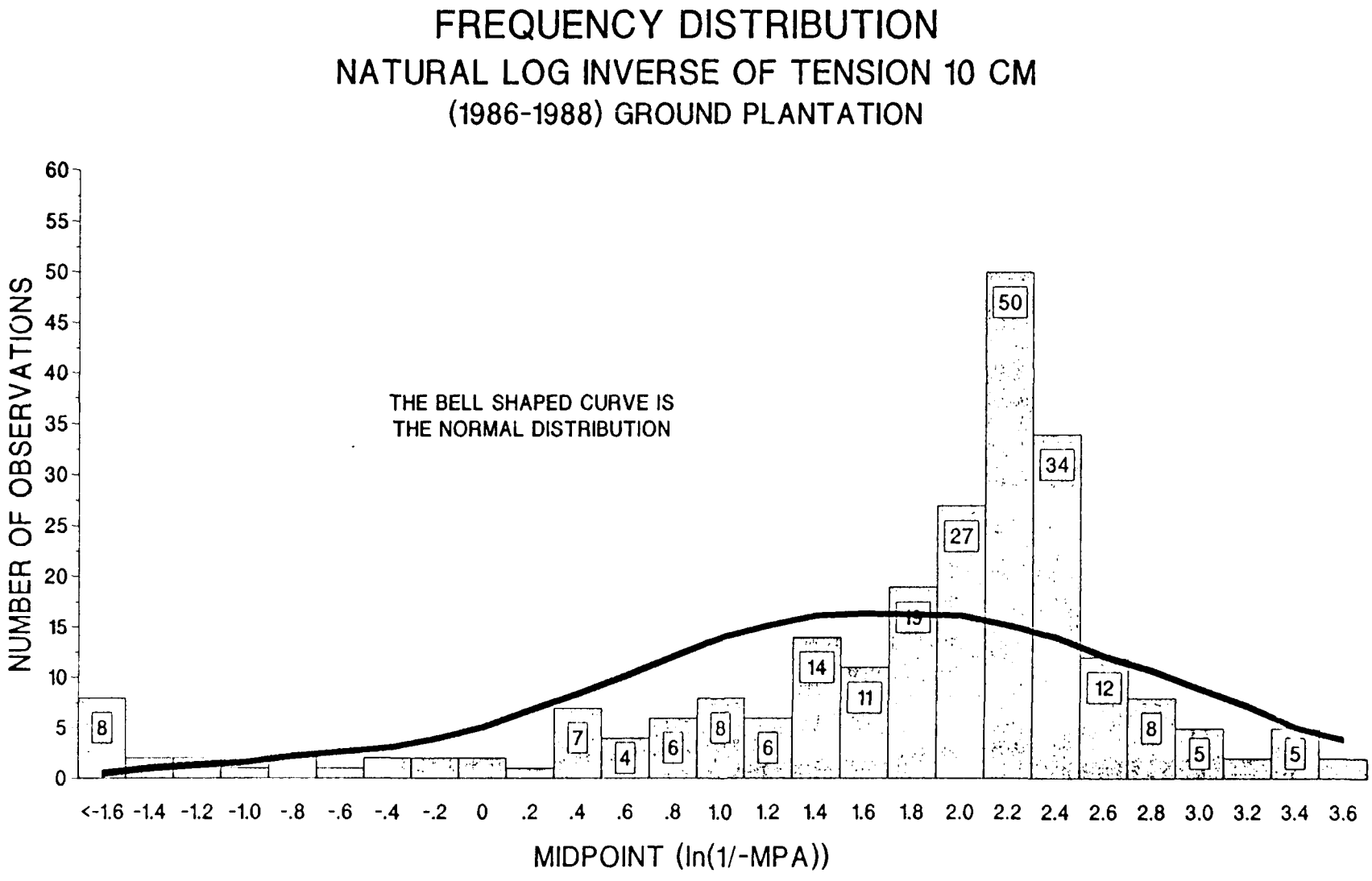
Table 1.9 Normality measurements for soil moisture 10cm, soil tension 10cm, and natural logarithm inverse soil tension 10cm for the ground site (1986-1988).

	Soil Moisture Moisture	Soil Tension	Nat. Logarithm Inverse
Kurtosis	.456	29.29	1.601
Skewness	-.492	5.31	-1.048
K-S Test			
(Statistic)	1.26	6.18	2.215
(Prob.)	.082	<.001	<.001

Soil Moisture (depth 5cm)

Site Comparisons: Average soil moisture content (5cm) at the control site over the past three years has been consistently higher than at the two test sites (Table 1.10, Figures 1.14-1.16). However, these differences were only significant for the control vs antenna comparison (p=.003). ANOVA tests also indicated significant site by treatment interactions (p=0.023). Multiple range tests showed that soil moisture content was significantly greater (p=.05) at the control than at the antenna for the plantation stand type but not the hardwood stand type.

Figure 1.13.


FREQUENCY DISTRIBUTION
NATURAL LOG INVERSE OF TENSION 10 CM
(1986-1988) GROUND PLANTATION
THE BELL SHAPED CURVE IS
THE NORMAL DISTRIBUTION
NUMBER OF OBSERVATIONS
0
5
10
15
20
25
30
35
40
45
50
55
60
8
7
4
6
8
6
14
11
19
27
50
34
12
8
5
5
<-1.6 -1.4 -1.2 -1.0 -.8 -.6 -.4 -.2 0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6
MIDPOINT (ln(1/-MPA))

Differences in the soil moisture relationships of the stand types between sites is a result of different factors controlling soil moisture in the two stand types. In the plantations the red pine have not yet occupied the available growing space and soil as fully as the trees have in the hardwood stands. As a result evapotranspiration rates in the plantation are lower than in the hardwood stands. Thus soil characteristics such as water holding capacity have a greater effect on the soil moisture content in the plantations than in the hardwoods. However in the hardwoods where evapotranspiration rates are high, factors such as stand density, species composition, and productivity have a much greater influence on moisture content.

Previous information on the soil characteristics of the sites has shown that soils at the control site are finer textured and have a higher water holding capacity than the soils at the antenna site. Thus higher soil moisture contents at the control plantation can be related to the higher moisture holding capacity at this site. However the effect of the higher water holding capacity at the control appears to be minimized in the hardwood stand due to the greater standing basal area of trees, growth, and thus evapotranspiration at the control compared to the antenna hardwood stand.

When soil moisture tension is used to compare sites, the control was found to have the lowest tension in the plantation stand type and highest tension in the hardwood stand type (Table 1.10). No significant differences were found between the control site and the ground ($p=.116$) but differences between the control and antenna were significant ($p=.006$).

Annual Comparisons: Differences between years were significant for all site comparisons. Multiple range tests showed that moisture content was significantly higher 1986 than in 1988 for both the control vs antenna and control vs ground comparisons. Only the control vs antenna comparison showed differences between 1986 and 1987 (Table 1.10). Annual comparisons for soil tension showed significant differences for the control vs antenna comparison ($p=.015$) but not the control vs ground comparison ($p=.124$).

One factor which tends to be uniform for all sites is the relationship of seasonal moisture trends during the study period. Moisture content is lowest and tension highest during June and July (Figures 1.14-1.19) when precipitation is low and evapotranspiration is high.

Site by Year Interactions: Site by year differences for soil moisture 5cm were significant for the control vs antenna comparison ($p<.001$) but not for the control vs ground comparison ($p=.187$). ANOVA tests indicated similar

Table 1.10 Comparisons of soil moisture content (5cm) and soil moisture tension (5 cm) during the 1986-1988 growing seasons.

Soil Moisture Content (5 cm)
%

	Plantation Stand Type				Hardwood Stand Type			
	1986	1987	1988	$\bar{X}$	1986	1986	1987	$\bar{X}$
Control	16.0	13.5	12.9	14.1	14.1	10.9	10.6	11.9
Antenna	9.2	11.3	11.3	10.6	10.4	10.8	9.5	10.2
Ground	13.2	13.6	11.8	12.9				

Tension (5 cm)
-Mpa

	1986	1987	1988	$\bar{X}$	1986	1987	1988	$\bar{X}$
Control	.028	.026	.076	.043	.069	.100	.165	.113
Antenna	.060	.022	.071	.051	.090	.062	.093	.082
Ground	.046	.069	.090	.068				

Site Comparison

	Control	Ground
Soil Moisture (5 cm) %	14.1 a[1/]	12.9 a
Tension (5 cm) -Mpa	.043 a	.068 a

	Control	Antenna
Soil Moisture (5 cm) %	13.0 a	10.6 b
Tension (5 cm) -Mpa	.078 a	.066 b

Annual Comparison

	Control vs Ground			Control vs Antenna		
	1986	1987	1988	1986	1987	1988
Soil Moisture (5 cm) %	14.6b	13.6ab	12.4a	12.4b	11.6a	11.1a
Tension (5 cm) -Mpa	.037a	.048a	.083a	.062a	.058a	.101b

[1/]Site or years with the same letter for a specific site are not significantly different (p=.05)

Figure 1.14.

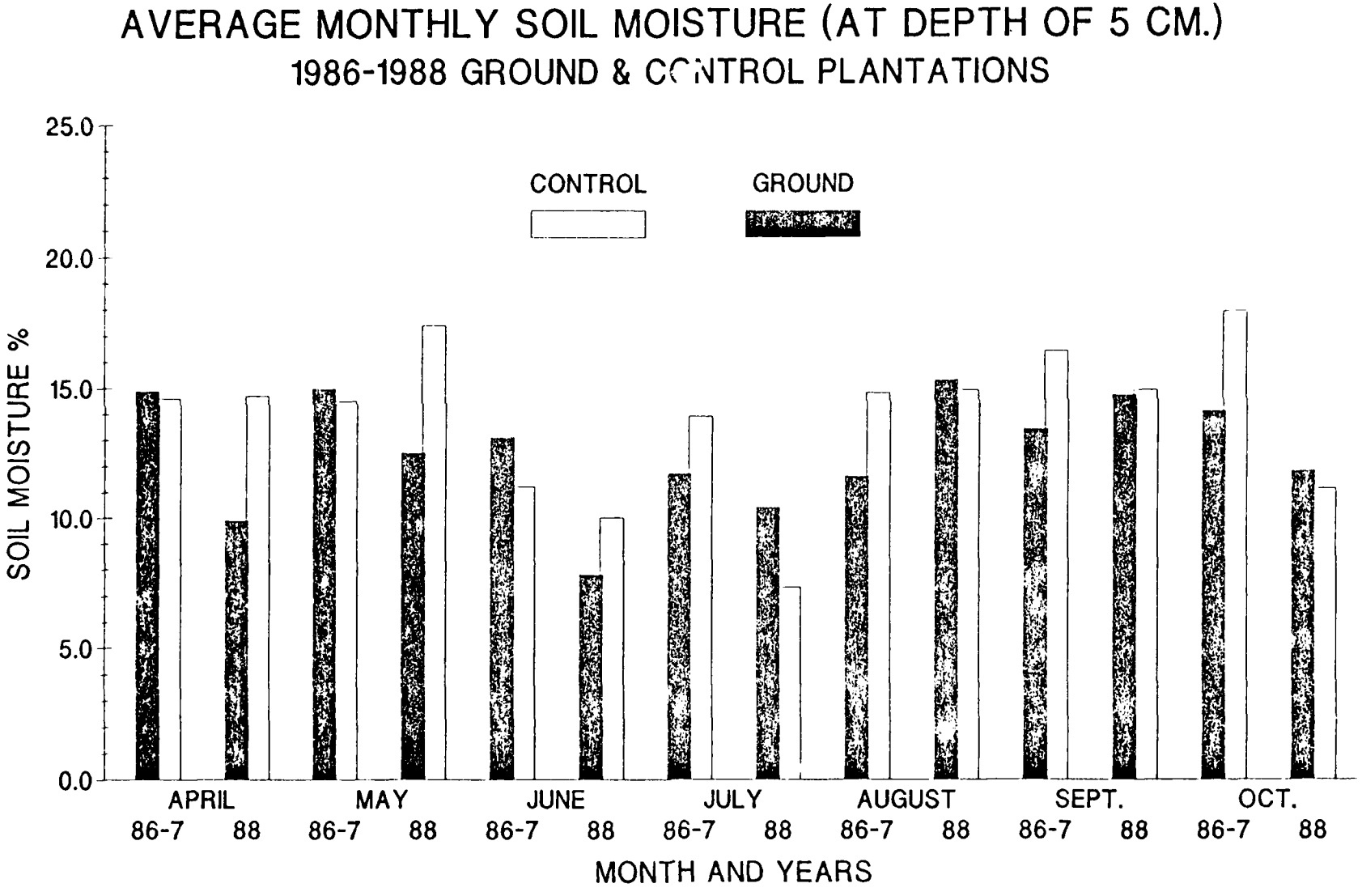

AVERAGE MONTHLY SOIL MOISTURE (AT DEPTH OF 5 CM.)
1986-1988 GROUND & CONTROL PLANTATIONS
CONTROL
GROUND
SOIL MOISTURE %
25.0
20.0
15.0
10.0
5.0
0.0
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
86-7
88
MONTH AND YEARS

Figure 1.15.

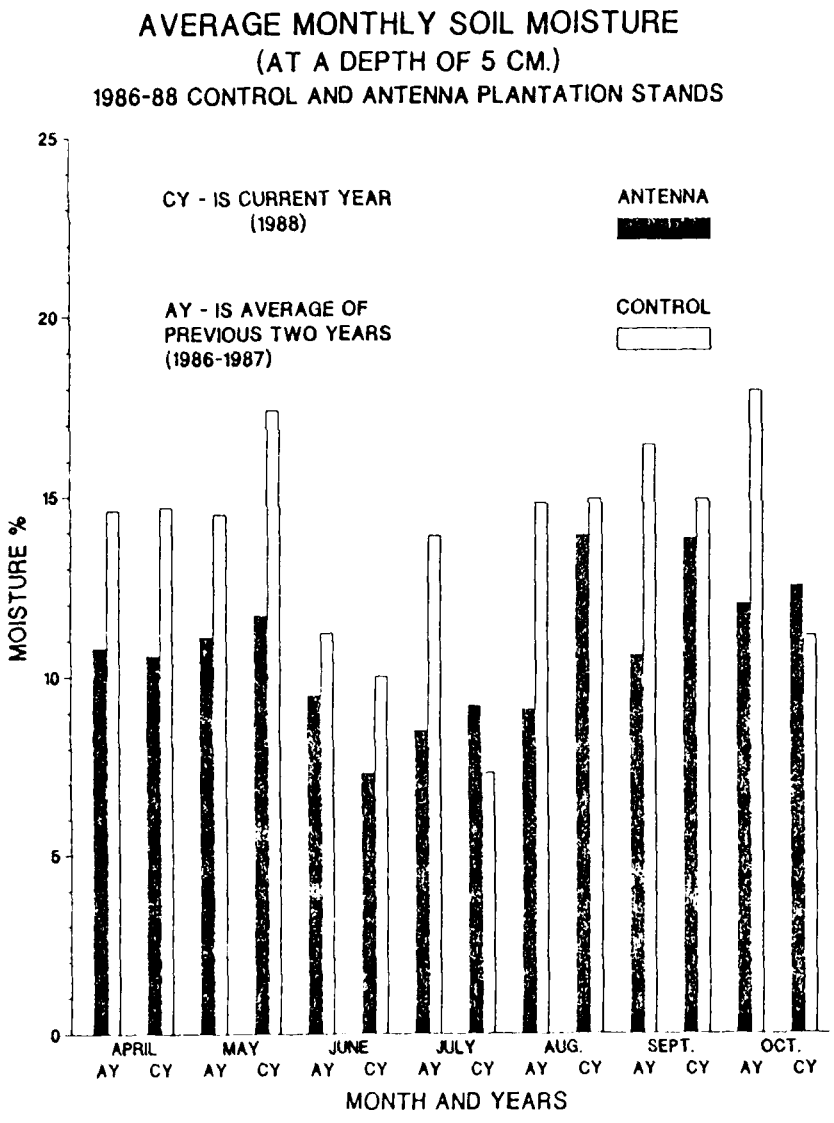
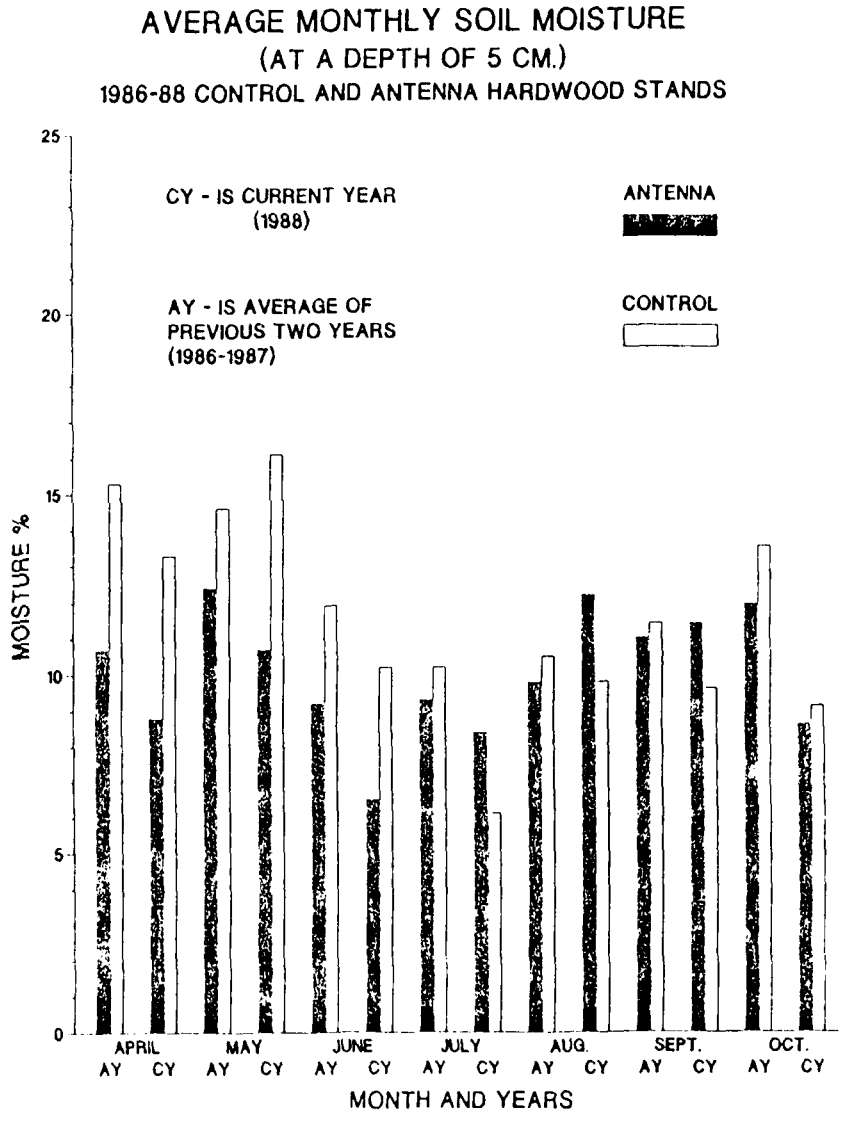


Figure 1.16.



relationships for site by year factors for soil tension. Multiple range tests ranked the site by year groups in the following order: control 86>control 87=control 88>antenna 87= antenna 88>antenna 86. Significant site by year interactions appear to be a related to soil moisture conditions during 1986. During 1986 the control had its highest average moisture content during the study period while the antenna had the lowest moisture content during the three year interval. Site by stand type by year interactions for both soil tension and soil moisture content at 5cm were nonsignificant (p=.402 and p=.090).

Detection Limits and Summary: Detection limits associated with soil moisture and tension are much higher than detection limits associated with temperature variables (Table 1.11). The moisture content detection limits for the control vs antenna comparisons have decreased compared to the detection limits computed in last years analyses. Detection limits (expressed as a % of the mean) computed from the logarithm of the inverse of soil tension (5cm) were much smaller than detection limits computed from the untransformed tension analyses in 1987. Site factor detection limits (expressed as a % of mean) for the control vs antenna comparison were reduced 10 fold. Detection limits for the transformed tension variable are still 2 to 4 times greater than the detection limits for the same factor for soil content measurements.

Table 1.11 Detection limits (p=.05) associated with year and site factors for soil moisture content (5 cm) and soil moisture tension (5 cm) during 1986-1986.

Factor	Detection Limits Inv. Log[1] Tension	Moist. Content	% Mean Inv. Log Tension	Moist. Content
Site (Control vs Ground)				
Site	.116	1.82	30.1	13.40
Year	.120	1.53	26.3	11.29
Site x Year	.168	2.21	36.8	16.30
Site (Control vs Antenna)				
Site	.042	1.08	9.8	7.98
Year	.086	0.64	16.8	4.70
Site x Year	.121	0.88	23.7	6.49
Site x Stand Type	.172	1.32	40.6	9.74
Site x Stand Type x Year	.844	1.53	30.2	11.29

[1]Inverse Logarithm Tension

Figure 1.17.

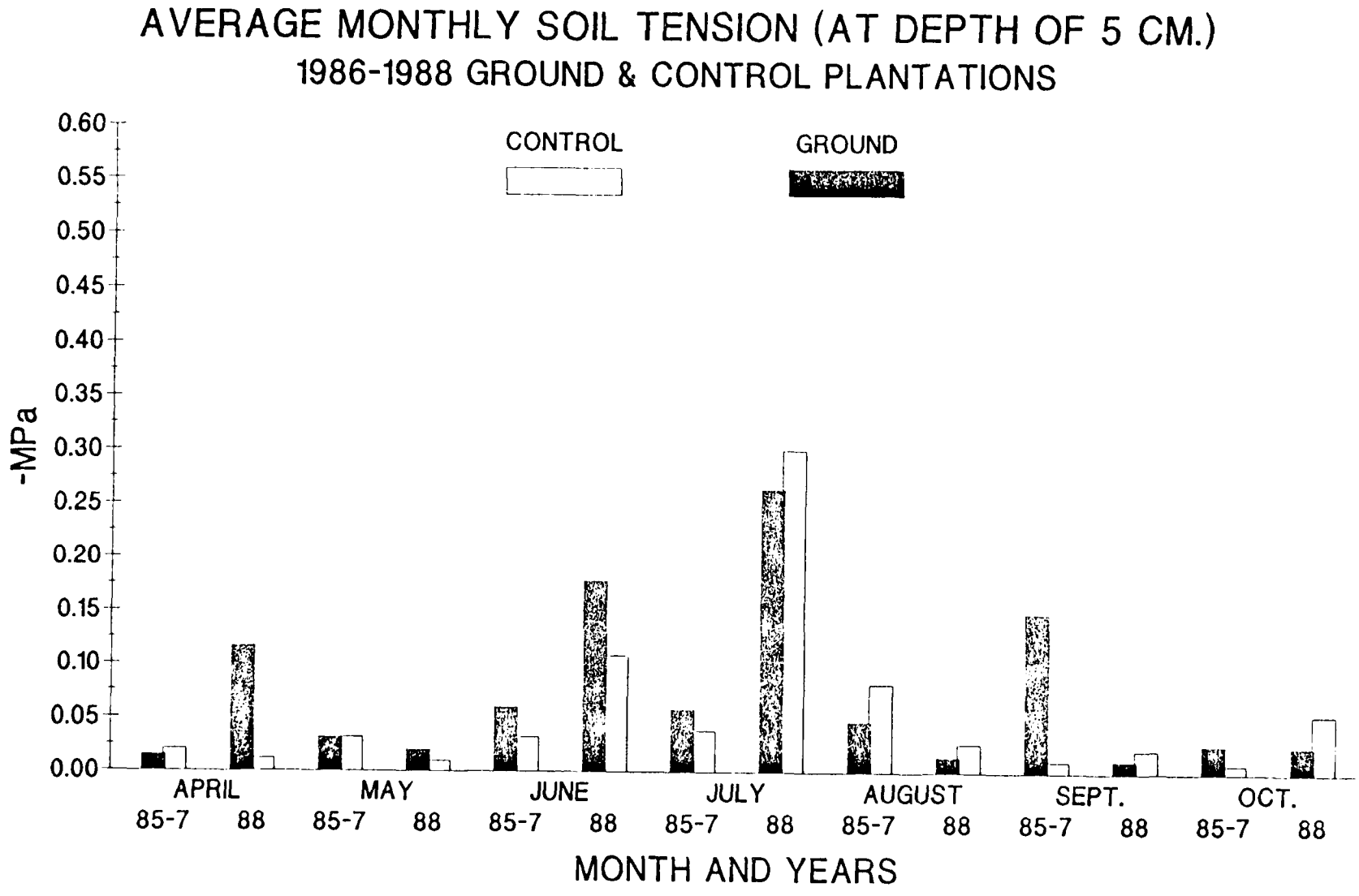

AVERAGE MONTHLY SOIL TENSION (AT DEPTH OF 5 CM.)
1986-1988 GROUND & CONTROL PLANTATIONS
CONTROL
GROUND
-MPa
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
85-7
88
MONTH AND YEARS

Figure 1.18.

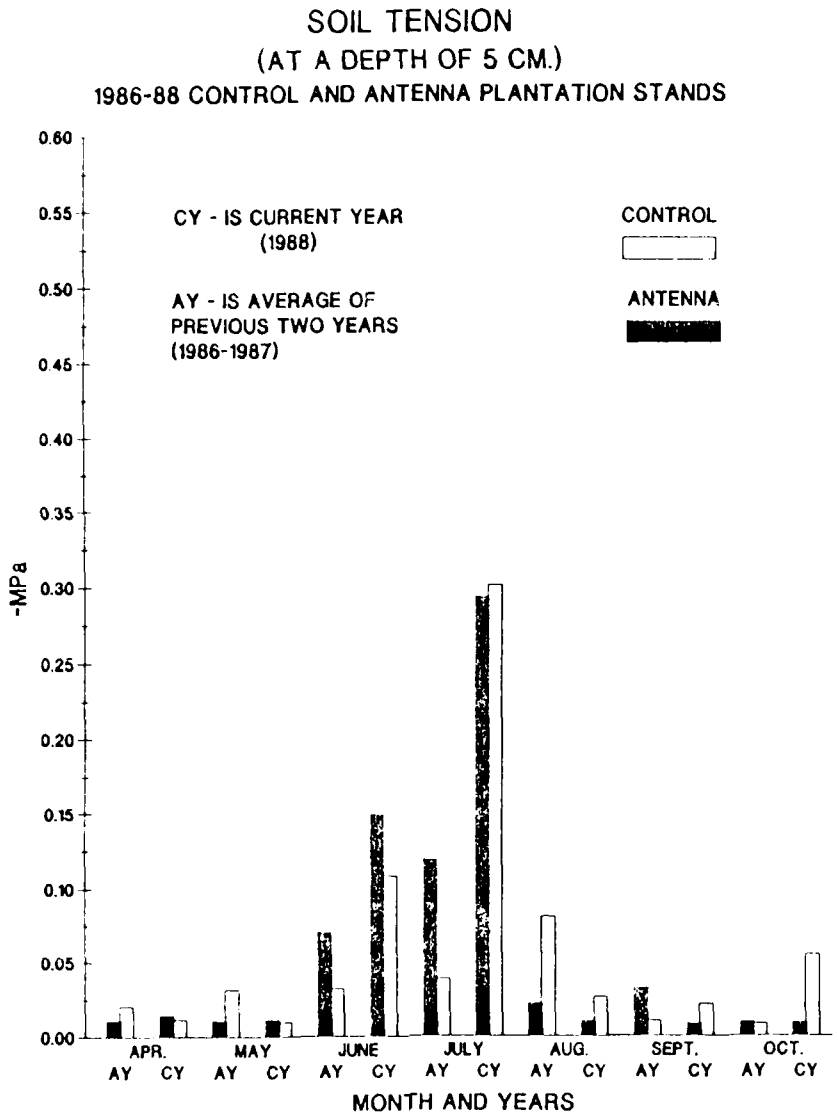
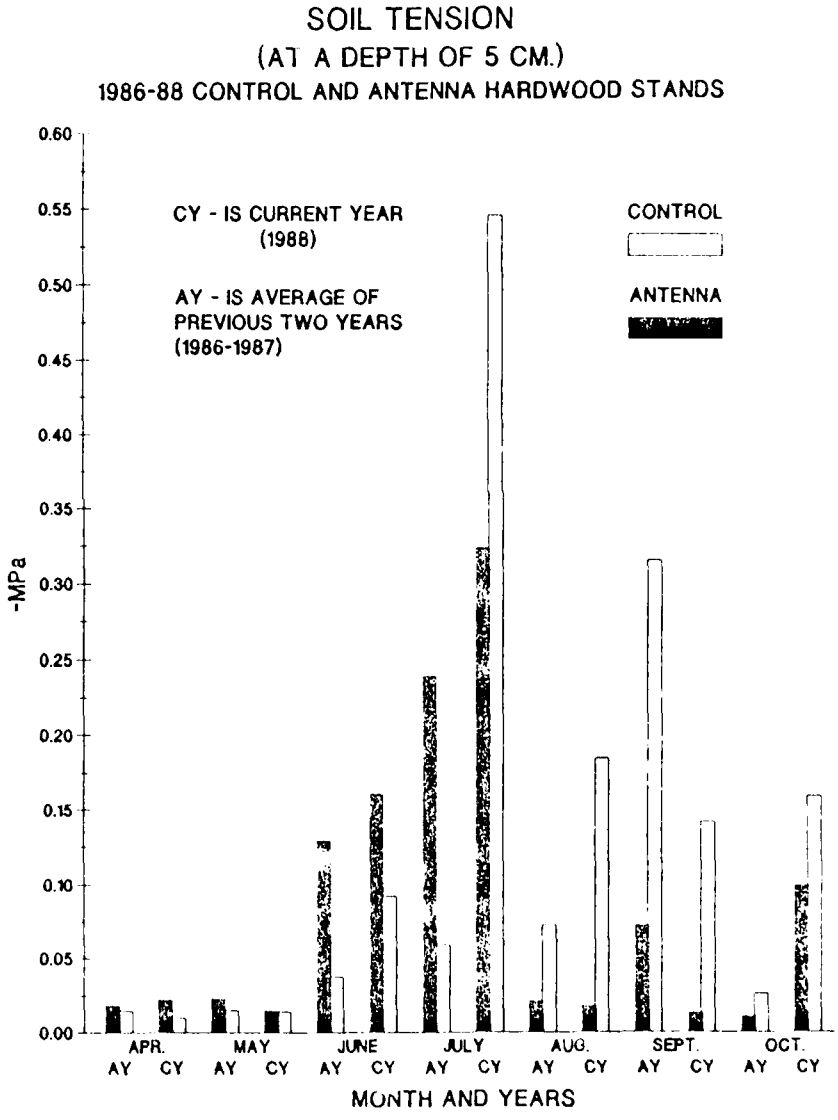


Figure 1.19.



As stated previously site by year and site by stand type interactions were significant for control vs antenna soil moisture content and soil tension comparisons. Site by stand type differences appear to be a result of factors other than ELF fields affecting moisture content and availability at the test sites. Significant differences for the site by year interaction do not appear to be as readily explained as did the site by stand type interaction. Thus at this time we can not rule out that the ELF fields have had a significant effect on soil moisture at 5cm.

Soil Moisture (depth 10cm)

Site Comparisons: Site relationships regarding soil moisture content at 10cm were similar to site relationships involving soil moisture content at depths of 5cm. Moisture contents at 10cm were consistently higher at the control site than at the test sites (Table 1.12). However, differences between sites were only significant for the control vs antenna comparison ($p=.008$). The control site also had lower soil tensions at depths of 10cm than did either of the test sites but differences were not significant for either the control vs antenna ($p=.658$) comparison or the control vs ground comparisons ($p=.650$).

Differences in moisture content (10cm) between the control and antenna sites in the hardwoods were less than differences between these two sites in the plantation stand type. These results were similar to results from the same comparison made for moisture contents at 5cm. Although site by stand type interactions were significant for the moisture content (5cm) comparisons, site by stand type interactions were not significant for moisture contents or soil tension at a depth of 10cm.

Annual Comparisons: ANOVA tests showed significant differences between years ($p=.004$) for the control vs ground comparison but not the control vs antenna comparisons ($p=.073$). Multiple range tests ranked the years in the following manner: 1986>1987>1988.

Site by Year Interactions: ANOVA tests for the control vs ground or control vs antenna comparison showed no significant site by year interactions for soil moisture content ($p=.086$ control vs ground, $p=.457$ control vs antenna). ANOVA tests involving soil tensions showed similar results with nonsignificant differences for the control vs ground ($p=.827$) or control vs antenna ($p=.942$) comparisons. Moisture relations among sites at this depth have remained stable over the study period.

Table 1.12 Comparisons of soil moisture content (10cm) and soil moisture tension (10 cm) during the 1986-1988 growing season.

	Soil Moisture Content (10 cm) %							
	Plantation Stand Type				Hardwood Stand Type			
	1986	1987	1988	$\bar{X}$	1986	1987	1988	$\bar{X}$
Control	14.6	15.1	14.4	14.7	12.6	12.7	12.8	12.7
Antenna	10.1	9.8	10.3	10.1	10.0	11.2	10.5	10.6
Ground	15.2	14.2	12.9	14.1				

	Tension (10 cm) -Mpa							
	1986	1987	1988	$\bar{X}$	1986	1987	1988	$\bar{X}$
Control	.042	.023	.076	.047	.044	.038	.038	.040
Antenna	.027	.017	.079	.041	.052	.063	.070	.062
Ground	.058	.020	.081	.053				

Site Comparison

	Control	Ground
Soil Moisture (5 cm) %	14.7 a[1/]	14.1 a
Tension (5 cm) -Mpa	.047 a	.053 a

	Control	Antenna
Soil Moisture (5 cm) %	13.7 a	10.4 b
Tension (5 cm) -Mpa	.044 a	.052 a

Annual Comparison

	Control vs Ground			Control vs Antenna		
	1986	1987	1988	1986	1987	1988
Soil Moisture (5 cm) %	14.9c	14.7b	13.6a	11.8a	12.2a	12.0a
Tension (5 cm) -Mpa	.050a	.021a	.079a	.042a	.035a	.066a

[1/]Site or years with the same letter for a specific site combinations are not significantly different (p=0.05)

Detection Limits and Summary: Table (1.13) presents detection limits for soil moisture content (10cm) and soil tension (10cm). Detection limits for these variables and factors are similar to those for soil moisture at the 5cm depth. Again tension detection limits are relatively high compared to detection limits associated with moisture contents.

Table 1.13. Detection limits (p=.05) associated with year and site factors for soil moisture content (10 cm) and soil moisture tension (10 cm).

	Detection Limits		% Mean	
Factor	Log. Inv.[1] Tension	Moist. Content	Log Inv. Tension	Moist. Content
Site (Control vs Ground)				
Site	.686	1.74	39.7	12.21
Year	.378	.83	21.8	5.82
Site x Year	.532	1.15	30.7	8.10
Site (Control vs Antenna)				
Site	.361	1.85	21.8	15.63
Year	.218	0.68	13.2	5.74
Site x Year	.308	0.95	18.6	8.02
Site x Stand Type	.514	1.34	31.1	11.31
Site x Stand Type x Year	.573	1.23	34.6	10.39

[1]Logarithm inverse tension

Depending on the comparison made, site and/or year factors were found to be significantly different. Although these factors were found to be significantly different site by year interactions for soil moisture (10cm) analyses were not found to be significant. Since the relationships between sites have been stable during the study period and there are not detectable changes in stand type by site relationships during the study period, we have no evidence to conclude that ELF fields have had an effect on soil moisture at depths of 10cm.

Precipitation

The amount of precipitation and the distribution of precipitation over time are two primary factors controlling availability of water for plant growth. Thus precipitation

is an important factor in the climatic monitoring program.

Site Comparisons: Total precipitation received among the sites were similar during 1985-1988 (Table 1.14, Figure

Table 1.14. Comparison of average total weekly precipitation during the 1985-1987 growing season.

	Inches Precipitation				
	1985	1986	1987	1988	$\bar{X}$
Control	.77	.49	.70	.59	.64
Antenna	.97	.46	.73	.69	.71
Ground	.95	.48	.70	.71	.71

Average Weekly Precipitation (Site)

Control	Antenna
.64 a[1/]	.71 a

Control	Ground
.64 a	.71 a

Average Weekly Precipitation (Year)

Control & Antenna				Control & Ground			
1985	1986	1987	1988	1985	1986	1987	1988
.87 a	.47 b	.72 b	.68 b	.86 a	.48 a	.70 a	.68a

Sites or year comparisons with the same letter are not significantly different (p=.05).

1.20). Differences between the control and test sites during 1985 were generally due to the precipitation collector's failure during two storm events at the control site. However in 1988 the control site received between .10 and .11 inches/week less precipitation than the tests sites (Table 1.14). In 1988 differences in the amount of precipitation received at the control and test sites were not apparent until June or July (Figure 1.21). ANOVA tests showed no significant differences between the control and ground site (p=.394) or the control and antenna site (p=.404).

Annual Comparisons: Average amount of precipitation during a week in 1988 was approximately .20 inches and .03 inches less than in 1985 and 1987 respectively and .20 inches more than in 1986 (Table 1.14). ANOVA tests showed significant differences among years for the control vs. antenna comparison (p=0.054). Tests with the control vs. ground combination (p=0.070) were not significant at p=0.05. Multiple range tests ranked the precipitation of the four years in the following manner 1985>1987=1988=1986.

Site by Year Comparisons: No significant differences were found for site by year interactions in either the control vs ground comparison (p=0.878) or the control vs antenna comparison (p=0.862).

Detection Limits: Since only one precipitation collector is located at each site, detection limits for

Table 1.15 Detection limits (p=.05) associated with year and site factors for average weekly precipitation (1985-1988).

Factor	Detection Inches	% Mean
Site (Control vs Ground)		
Site	.192	28.9
Year	.258	39.0
Site x Year	.365	55.1
Site (Control vs Antenna)		
Site	.194	29.3
Year	.264	39.8
Site x Year	.374	56.5

Figure 1.20.

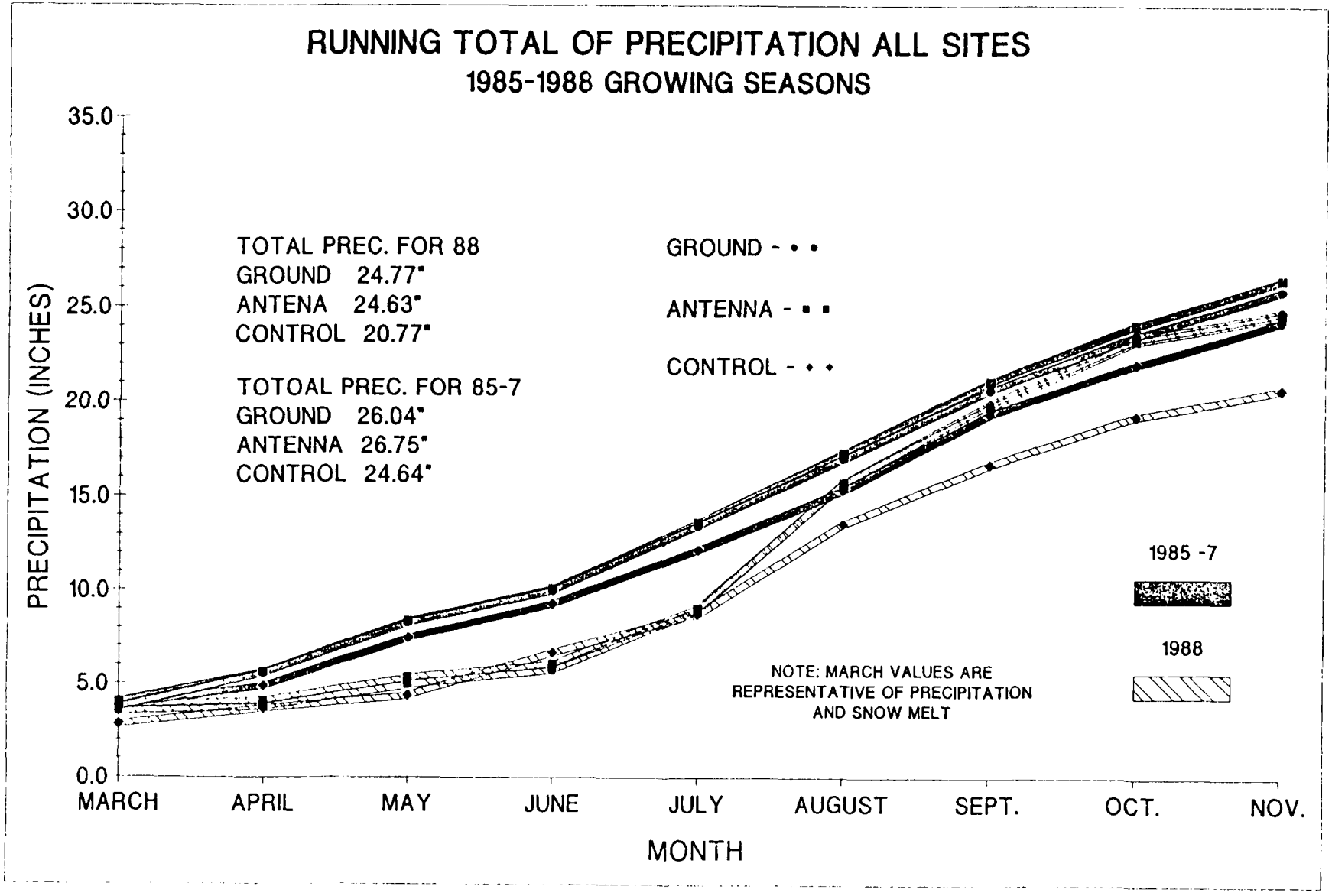
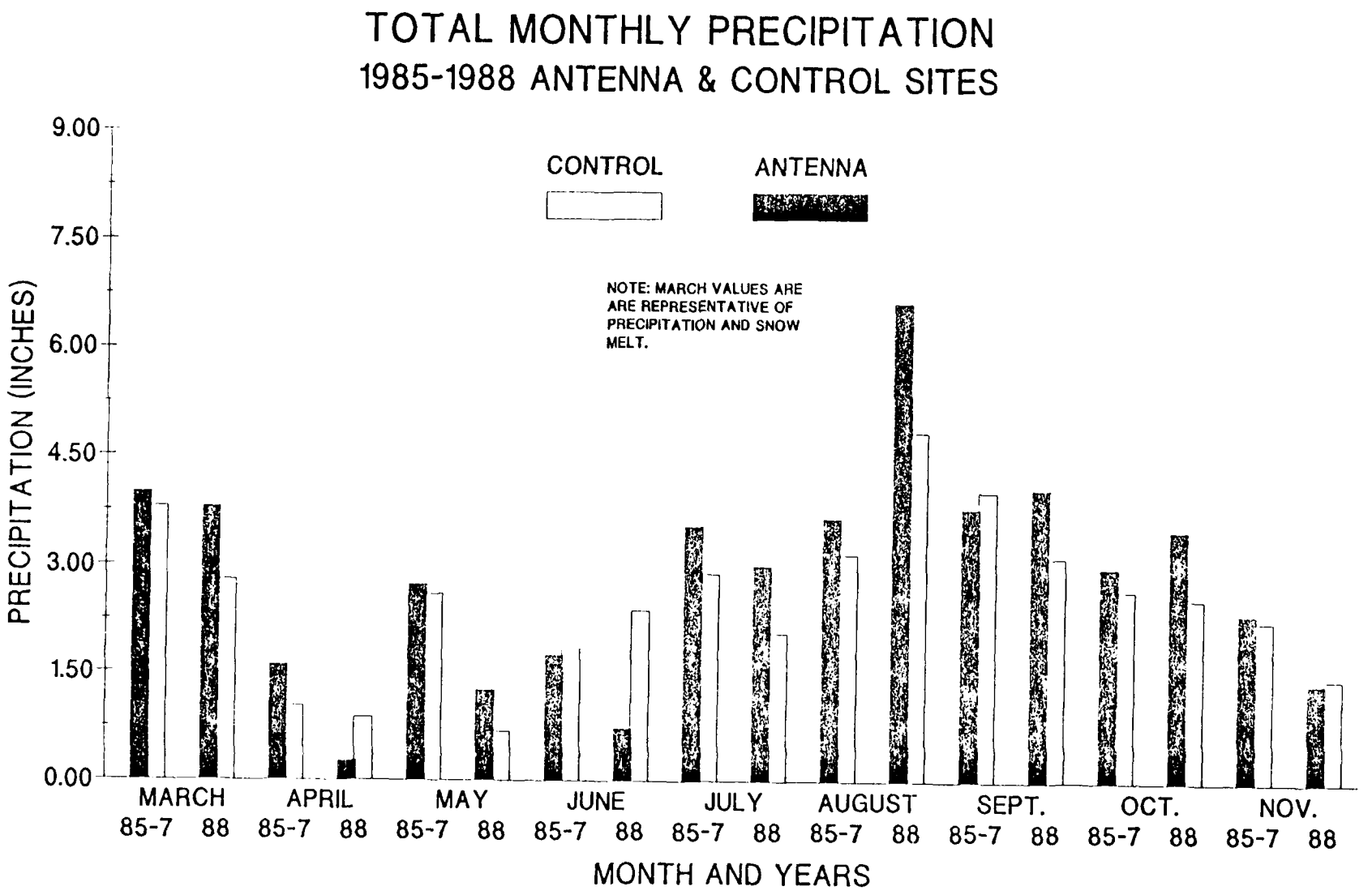

RUNNING TOTAL OF PRECIPITATION ALL SITES
1985-1988 GROWING SEASONS
PRECIPITATION (INCHES)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
TOTAL PREC. FOR 88
GROUND 24.77"
ANTENA 24.63"
CONTROL 20.77"
TOTOAL PREC. FOR 85-7
GROUND 26.04"
ANTENNA 26.75"
CONTROL 24.64"
GROUND - • •
ANTENNA - ▪ ▪
CONTROL - ◆ ◆
1985 -7
1988
NOTE: MARCH VALUES ARE REPRESENTATIVE OF PRECIPITATION AND SNOW MELT
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
NOV.
MONTH

Figure 1.21.


TOTAL MONTHLY PRECIPITATION
1985-1988 ANTENNA & CONTROL SITES
CONTROL
ANTENNA
NOTE: MARCH VALUES ARE ARE REPRESENTATIVE OF PRECIPITATION AND SNOW MELT.
PRECIPITATION (INCHES)
9.00
7.50
6.00
4.50
3.00
1.50
0.00
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
NOV.
85-7 88
MONTH AND YEARS

precipitation are relatively high (Table 1.15). Detection limits were between 38.9% and 56.5% of the average weekly total precipitation. The detection limits calculated this year for site and site by year interactions were smaller than last year's calculations.

An additional precipitation collector at each site would probably increase the statistical accuracy of our analysis. However rainfall is extremely homogeneous over the area of a given study site. Thus any variation between the collectors would only be due to variation of the equipment and would not give a more accurate measurement on the amounts of rainfall.

Precipitation collectors are located in the plantations and the amounts of rainfall collected are not effected by the vegetation at the plantation. Thus precipitation is considered to be independent of ELF effects and no discussion relative to ELF exposure is included with this section.

Global Solar Radiation

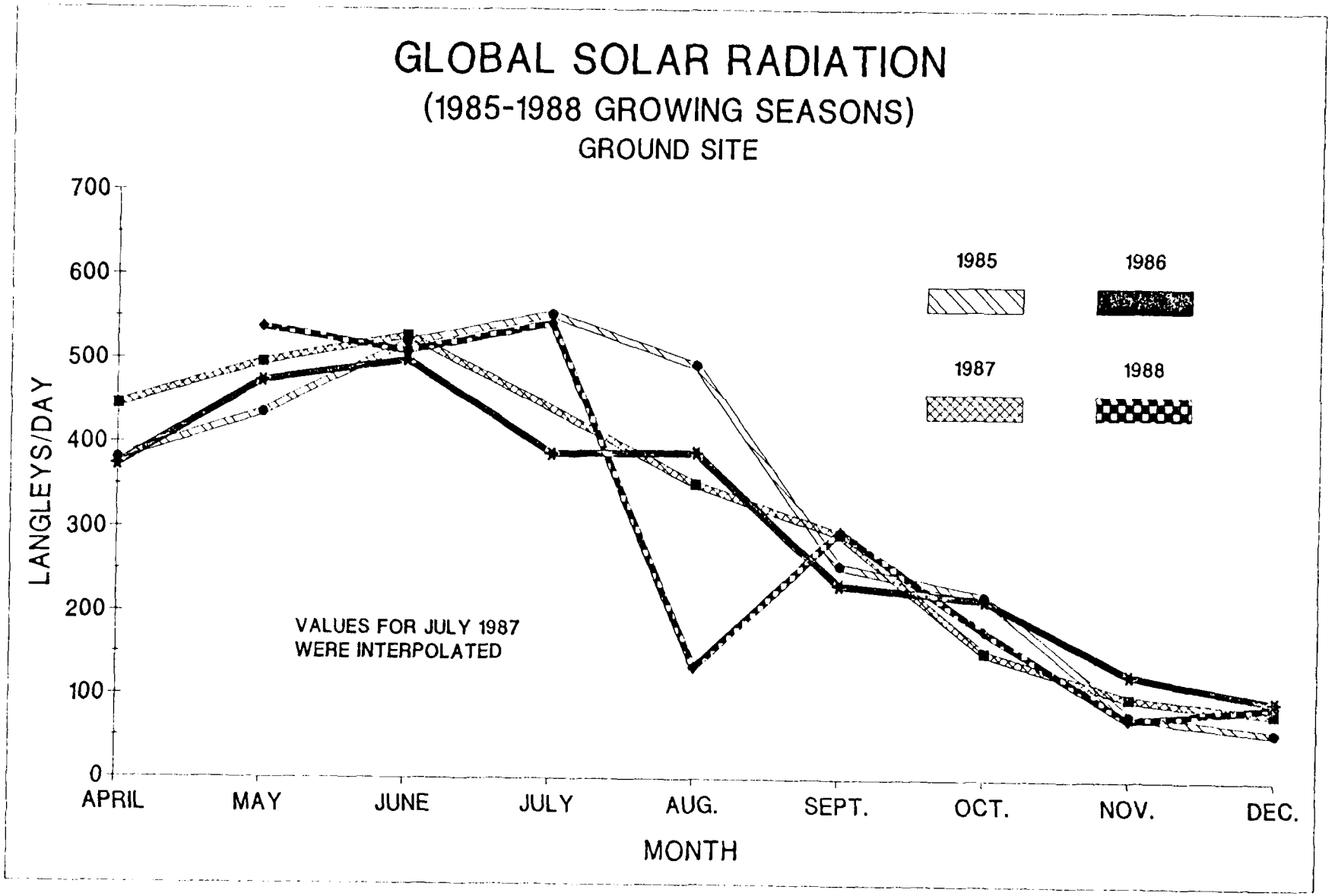
Solar radiation is the primary energy source for photosynthesis as well as the primary factor controlling climatic conditions. Thus solar radiation is continually monitored at the study sites.

Comparisons of global solar radiation did not include July of 1987 or April of 1988. Data from July of 1987 was not available due to the lightning strike at the ground site and the sensor was being calibrated during April of 1988. Thus it was felt that a more suitable comparison of yearly information could be made if April and July were excluded of the analyses.

Annual Comparisons: Average daily global solar radiation for each month of the growing season is presented in Appendix B (Table 9). ANOVA tests were performed on only May, June, August, September, and October measurements due to sensor failure in July of 1987 and sensor calibration in April of 1988. Measurements of global solar radiation in August of 1988 were low because 16 days of measurements were missing due to a computer failure (Figure 1.22). Average daily global solar radiation during the adjusted 1985 growing season was 24.1, 20.4, and 54.0 Langleys/day higher than in the years 1986-1988 respectively (Table 1.16). However differences between years were not significant ($p=0.993$).

Analyses in 1986 indicated significant year by month interactions. The analysis in 1986 included the month of July because the solar radiation sensor was operational in July for both 1985 and 1986. This years analysis which excluded this month did not find a significant month by year interaction ($p=0.822$). Global solar radiation is generally

Figure 1.22.


GLOBAL SOLAR RADIATION
(1985-1988 GROWING SEASONS)
GROUND SITE
LANGLEYS/DAY
700
600
500
400
300
200
100
0
1985
1986
1987
1988
VALUES FOR JULY 1987
WERE INTERPOLATED
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
MONTH

the highest in June and July (Figure 1.22). Thus missing

Table 1.16. Average global solar radiation during the 1985-1987 adjusted growing seasons and detection limits for year and month by year factors (p=.05)

Global Solar Radiation[1/] (Langleys/Day)			
1985	**1986**	**1987**	**1988**
385.1 a[2/]	360.9 a	364.6 a	331.0

Factor	Detection Limit (Langleys/Day)	% Mean
Year	71.5	20.3
Year x Month	103.3	29.3

[1/]Averages and analysis using May-June, August-October. July was excluded from the analysis due to missing information from July 1987 and April 1988.

[2/]Years with the same letters are not significantly different (p=0.05).

observations from these two months appear to critically affect the outcome of the statistical analyses.

Detection Limits and Summary: The detection limits for the year and the year by month factors were 71.5 and 103.5 Langleys/day respectively (Table 1.16). Although detection limits were lower this year than last, detection limits expressed as a % of the mean were higher than the same statistic last year.

The global solar radiation sensor is located about 4 meters above the ground in the plantation at the ground site. Thus global solar radiation is independent of ELF fields.

Relative Humidity

Atmospheric humidity is an influential factor determining rates of plant transpiration and respiration. Humidity is related to vapor pressure gradients which influence the amount of transpiration and evaporation from a given land area. In an attempt to fully monitor the climate

at the study sites, relative humidity is measured by the ambient monitoring systems.

As a result of sensor repairs and system failures this is the second year that relative humidity has been monitored during the entire growing season. Thus annual comparisons and site comparisons are limited to 1987 and 1988.

Site Comparisons: In 1987 and 1988 relative humidity was higher at the test sites than at the control site (Table 1.17 Figure 1.23). Differences were significant ($p=.043$) for the control vs antenna but not significant for the control vs ground comparisons ($p=.090$). Differences among months during the growing season were significant ($p<.001$) for both comparison but month by site interactions were not significant.

Seasonally relative humidity increases from April through July and then stabilizes after July (Figure 1.23). Statistical tests showed seasonal trends to be stable among the sites and years (1987-1988) (Figure 1.23).

Annual Comparisons: Differences between 1987 and 1988 were significant for the control vs antenna comparisons ($p=0.005$) and the control vs ground comparison ($p=0.024$). Differences between years was between 4 and 5% relative humidity depending on the sites used for comparison.(Table 1.17).

Site by Year Interactions: Site by year interactions were not significant for the control vs ground comparisons ($p=0.151$) but were significant for the control vs antenna comparisons ($p=0.019$). Multiple range tests ranked average relative humidity for each site and year in the following order : Antenna 87>Antenna 88>Control 87>Control 88. Differences in average relative humidity among sites and between years correspond to differences in precipitation among the sites and between years. Generally 1988 was a drier year than 1987 and thus humidity was lower also. The control site also received less rainfall than the test sites in 1988 and had a lower average relative humidity than the test sites during this year.

Detection Limits and Summary: Site and year factors had low detection limits for each of the site comparisons. These limits were among the lowest calculated for the climatic variables measured. However the sensors themselves have a larger equipment error than a temperature sensors. Humidity sensors have to be calibrated often to maintain an accuracy level of +/- 2%. These sensors are calibrated in the early spring and sometimes wander from the proper

calibration during the summer. Thus detection limits associated with the statistical analysis may not accurately reflect actual differences which can be detected for a given factor.

Table 1.17 Comparison of relative humidity during the 1986 and 1987 growing seasons and detection limits associated with site and year factors (p=0.05).

	Relative Humidity (1987-1988) %		
	1987	1988	$\bar{X}$
Control	67.7	60.8	64.2
Antenna	82.2	77.2	79.7
Ground	78.7	77.2	78.0

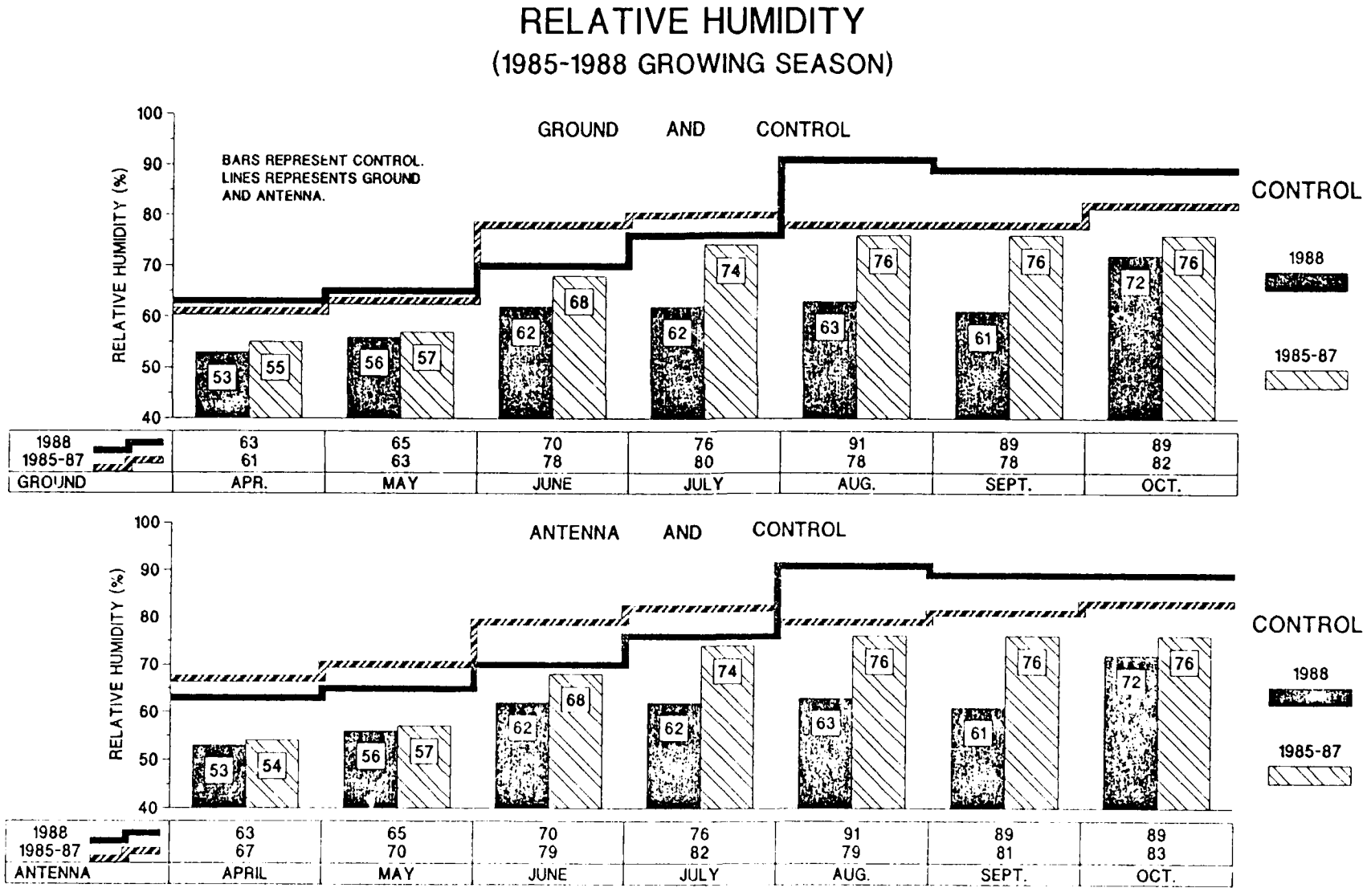
	Relative Humidity %	
	1987	1988
Control vs Antenna	75.0 a[1/]	69.0 b
Control vs Ground	73.2 a	69.0 b

	Detection Limits %	% Mean
Control vs Antenna		
Site	1.38	2.02
Year	3.77	4.78
Year by Site	5.16	6.56
Control vs Ground		
Site	1.94	2.65
Year	3.48	4.42
Year by Site	4.92	6.24

[1/] Year or site comparisons with the same letter for a specific site combination are not significantly different (p=0.05)

Relative humidity sensors are located 2 meters above the ground at the plantations. At this time the vegetation in the plantations should not have any substantial effect on relative humidity. Although significant site by year

Figure 1.23.


RELATIVE HUMIDITY
(1985-1988 GROWING SEASON)
GROUND AND CONTROL
BARS REPRESENT CONTROL.
LINES REPRESENTS GROUND
AND ANTENNA.
RELATIVE HUMIDITY (%)
100
90
80
70
60
50
40
53
55
56
57
62
68
62
74
63
76
61
76
72
76
CONTROL
1988
1985-87
1988 63 65 70 76 91 89 89
1985-87 61 63 78 80 78 78 82
GROUND APR. MAY JUNE JULY AUG. SEPT. OCT.
ANTENNA AND CONTROL
RELATIVE HUMIDITY (%)
53
54
56
57
62
68
62
74
63
76
61
76
72
76
CONTROL
1988
1985-87
1988 63 65 70 76 91 89 89
1985-87 67 70 79 82 79 81 83
ANTENNA APRIL MAY JUNE JULY AUG. SEPT. OCT.

interactions were found for the control vs antenna comparisons, the multiple range tests did not indicate any trend which could be related to ELF effects. Significant site by year interactions may have been caused by the recalibration of the sensors and the large sensor error associated with this variable.

Photosynthetically Active Radiation (PAR)

Photosynthetically active radiation is measured in the hardwood stand at the control an antenna sites. This climatic variable should be sensitive to possible ELF related changes in the canopy of the hardwood stand. Reduction of foliage biomass or changes in the timing of leaf expansion or leaf fall would alter the amount of radiation reaching the forest floor over the duration of the growing season. This type of change would effect forest floor vegetation growth and microclimate in the hardwood stands.

Sensor and system failures have limited the amount of months of data which can be used for this analysis. We have measurements for this variable for April through July of 1986-1988 and have used this data set for ELF effect testing. Measurements during this time span should give a good indication of any changes in leaf area or timing of leaf expansion between the control and test sites.

Site and Annual Comparisons: Comparisons of sites and years are limited to the months of April through June, due to the downtime of the platforms. Since PAR sensors were not operational until June of 1985, 1986 through 1988 are the only years used in PAR comparisons. Figure (1.24) shows that PAR is dramatically reduced during May and June when leaf expansion of the hardwood stands occur.

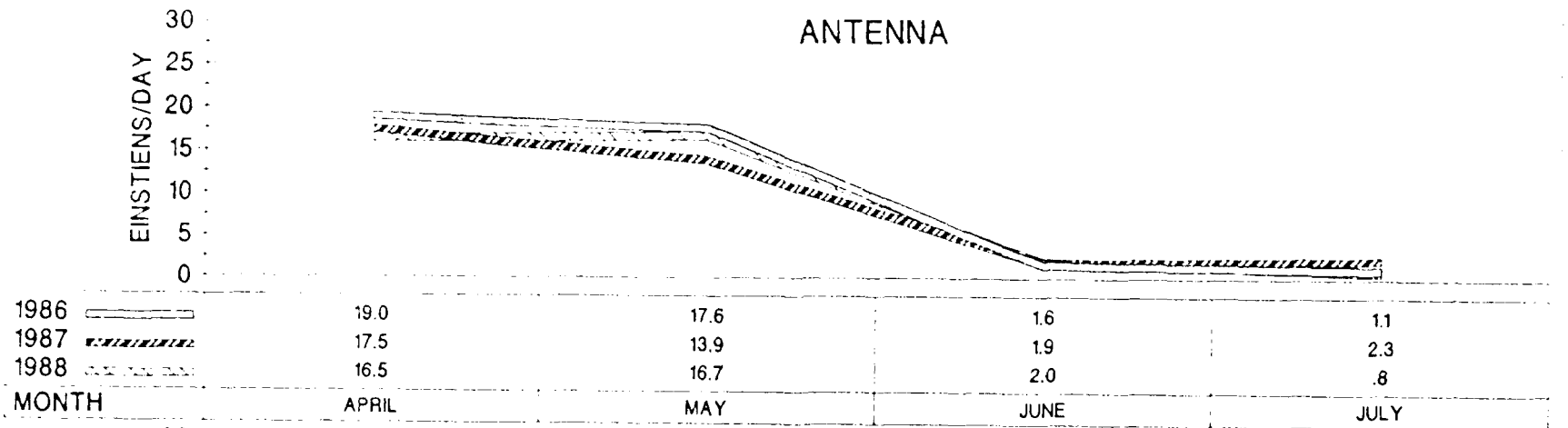
Averages of PAR were 2.77 Einsteins/day higher at the antenna site than at the control site during 1986-1987 but .59 Einsteins/day lower in 1988. Average PAR also increased 1.39 Einsteins/day during the three years of measurements (Table 1.18) Neither of these two factors , site or year, were significant ($p=.240$ and $p=.091$). Site by year factors were also not significantly different ($p=.062$) for this analysis.

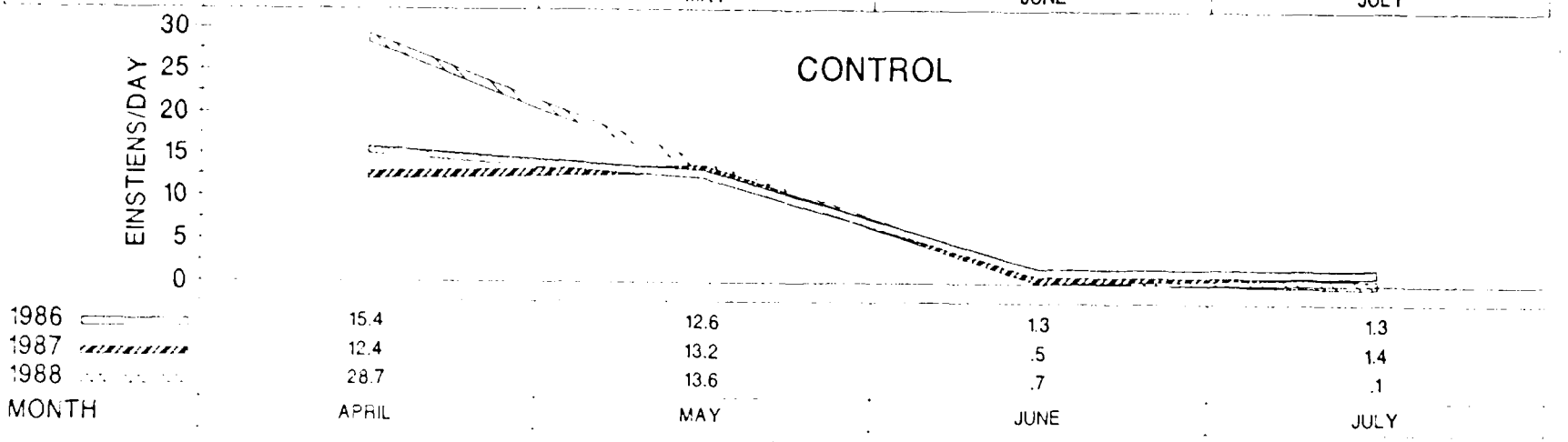
Detection Limits and Summary: Table (1.18) presents the detection limits for PAR. These values are similar to the limits calculated in 1987 and are indicative of ambient variables only measured on a site level.

Since no significant differences were found for the site, year, or site by year interactions, there was no evidence to indicate that the present levels of ELF exposure has affected PAR at the antenna hardwood site. However this

Figure 1.21.

PHOTOSYNTHETIC ACTIVE RADIATION
(1986-1988) GROWING SEASONS
(30 CM ABOVE GROUND IN HARDWOOD STAND TYPES)





was the first year that PAR at the control site was higher than at the antenna site.

Table 1.18. Comparison of photosynthetically active radiation during the 1986 and 1987 growing seasons and detection limits associated with site and year factors (p=0.05).

	Average Daily PAR[1/] (Einsteins/Day)			
	1986	**1987**	**1988**	**$\bar{X}$**
Control	5.87	5.57	8.60	6.68 a
Antenna	7.73	9.25	7.91	8.28 a[2/]
$\bar{X}$	6.80 a	7.85 a	8.19 a	

Factor	Detection Limits PAR	% Mean
Site	1.91	25.6
Year	1.09	14.6
Site x Year	1.73	23.2

[1/]Values determined for only April-July.

[2/]Site or year comparison with the same letter are not significantly different at (p=.05).

Air Temperature (30cm above ground)

Air temperature is being monitored 30cm above the ground to give more accurate measurements of climatic conditions at the understory air interface. These sensors were not operational in 1987 and thus analyses and summaries were only performed on the 1985, 1986, and 1988 measurements.

Site Comparisons: Average air temperature 30cm above the ground was .9 ^{o}C warmer at the control than at the antenna hardwood stand for the three years of measurements (Table 1.19). ANOVA tests showed significant differences between the sites (p=0.019). Temperature differences between sites for air temperature at 30cm (.9^{o}C) were equal to temperature differences between sites for air temperature at 2m.

Annual Comparisons: Average air temperature (30cm) was 1.0°C and .4°C warmer in 1988 than in 1985 and 1986 respectively. However no significant differences (p=.311) were found for the year factor in ANOVA tests. Similar differences in air temperature at 2m were significantly different. The greater sensitivity of ANOVA tests for air temperature 2m are a result of the greater number of plots and thus sensors involved in the measurements.

Site by Year Interactions: Differences between the air temperature at the sites were greater in 1988 (1.3°C) than in 1985 or 1986 (.7°C) (Table 1.19, Figure 1.25). However no significant site year interactions were found by the ANOVA test (p=.836).

Detection Limits and Summary: Detection limits, although higher than detection limits for other temperature

Table 1.19 Comparison of air temperature 30cm above the ground at the control and antenna hardwood stands during 1985, 1986, 1988.

Average Daily Air Temperature 30cm [1/] (°C)

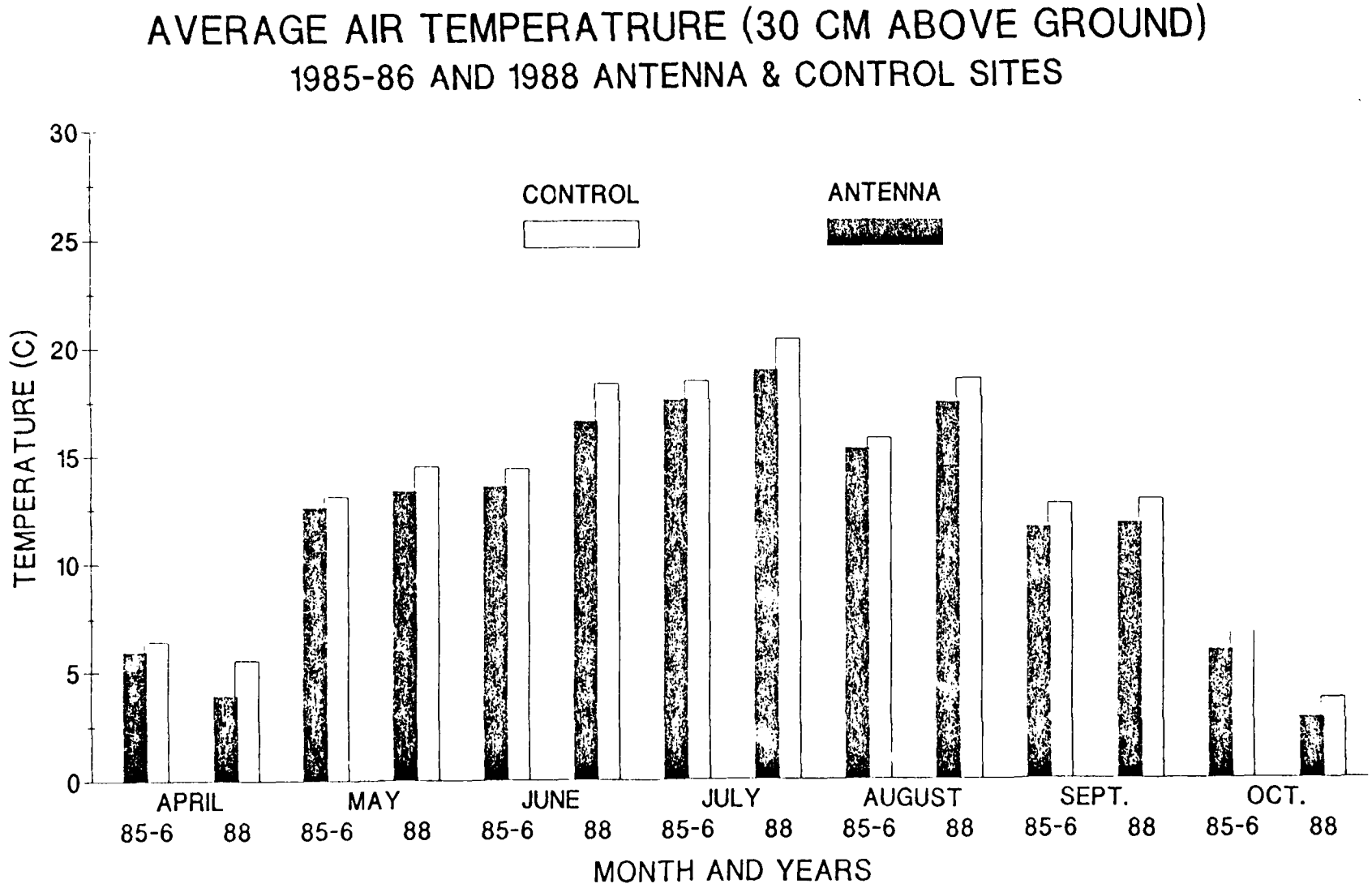
	1985	1986	1988	$\bar{X}$
Control	12.2	12.7	13.4	12.8 b
Antenna	11.5	12.0	12.1	11.9 a[2/]
$\bar{X}$	11.8 a	12.4 a	12.8a	

Factor	Detection Limits °C	% Mean
Site	.74	5.95
Year	1.29	10.4
Site x Year	1.82	14.7

[1/] Values determined for only 1985, 1986, and 1988

[2/] Site or year comparison with the same letter are not significantly different at (p=.05).

Figure 1.25.


AVERAGE AIR TEMPERATRURE (30 CM ABOVE GROUND)
1985-86 AND 1988 ANTENNA & CONTROL SITES
CONTROL
ANTENNA
TEMPERATURE (C)
30
25
20
15
10
5
0
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
85-6
88
MONTH AND YEARS

variables, are adequate considering the number of sensors used for the measurements. Given the results of the analyses for air temperature at 30cm we can not conclude the ELF has affected this ambient variable. If the trend of increasing differences between sites continues the possibility of ELF fields affecting this variable will be considered further.

Summary

A large number of climatic variables have been found to vary significantly among sites and/or years (Table 1.20-1.21). Air temperature (2m) and soil moisture content (5cm) are two climatic variables which have consistently differed among the control and tests sites. Air and soil temperature, soil moisture and tension, and precipitation change annually at the sites. Any of these climatic variables which differ among sites or years would be good candidates for modeling efforts or covariate analysis in the other elements of the project. However, before these climate variables are included in any final analyses, it must be shown that they are not correlated to ELF antenna operation.

We expect that any changes in a climatic variable as a result of ELF antenna operation would correspond to changes of the ecology at the test sites. To detect and quantify any changes in the climate at the test sites, comparisons of the climatic relationships between the control and test sites over the duration of the project are made. Changes in the relationships of the climate between the control and test sites would indicated possible ELF field effects on the ecology of the test sites. These changes are expressed in our statistical design through significant site by year and site by stand type by year interactions. To date air temperature (2m) site by year interactions have been significant for the control vs ground analysis and soil moisture content (5cm) and tension (5cm) site by year interactions have been significant for the control vs antenna comparisons (Table 1.20-1.21). At this time the climatic changes at the test sites do not appear to be related to any changes in the other abiotic or biotic parameters being monitored in the project. Thus at this time we cannot conclude that changes in air temperature (2m) or soil moisture measurements (5cm) at the test sites with respect to the control site are a response to ELF antenna operation.

Table 1.20 Significant differences for control vs ground site comparisons

	FACTOR		
Variable	Site	Year	Site by Year
Air Temp. (2m)	*[1]	*	*
Soil Temp. (5cm)	-	*	-
Soil Temp. (10cm)	-	*	-
Soil Moist. (5cm)	-	*	-
Soil Tens. (5cm)	-	-	-
Soil Moist. (10cm)	-	*	-
Soil Tens. (10cm)	-	-	-
Rel. Hum.	-	*	-
Precipitation.	-	-	-

[1] Factors denoted by * $p<=.05$.

Factors denoted by - $p>.05$

Table 1.21 Significant differences for the control vs antenna comparisons

	FACTORS				
Variable	Site	Year	Site by Year	Site by Stand Type	Site by Stand Type by Year
Air Temp. (2m)	*[1]	*	-	-	-
Soil Temp.(5cm)	-	*	-	*	-
Soil Temp.(10cm)	-	*	-	-	-
Soil Moist.(5cm)	*	*	*	*	-
Soil Tens.(5cm)	*	*	*	-	-
Soil Moist.(10cm)	*	-	-	-	-
Soil Tens.(10cm)	-	-	-	-	-
PAR	-	-	-		
Air Temp.(30cm)	-	-	-		
Rel. Hum.	-	*	*		
Precipitation	-	*	-		

[1] Factors denoted by * p<=.05

Factors denoted by - p>.05

Nutrient Monitoring

Precipitation Chemistry

As part of the ambient monitoring program the nutrient contents of rainwater samples were determined to estimate nutrient inputs from precipitation at all three sites during the growing seasons. A collection bucket having a fitted funnel attachment was placed on one plantation plot at each study site. The buckets were checked once a week and if rainfall had occurred a water sample was removed for nutrient analysis. Phenolmercuric acetate was added to each bucket to prevent nutrient changes due to microbial activity prior to collection. The water samples were frozen and stored at $-7.8^{o}C$ until chemical analysis. Cation concentrations were determined on a Perkin-Elmer Model 5000 atomic absorption spectrometer. Anions were analyzed on a Dionex Model 10 ion chromatograph.

Progress

Comparisons of 1985 and 1986 precipitation chemistry were presented in the 1987 annual report. At this time laboratory analysis of precipitation from 1987 and 1988 is being completed.

Soil Nutrients

Tree productivity analysis completed during the past years have indicated that soil nutrients are valuable covariates in explaining site and year differences (see Element 2). In addition, analysis of northern red oak foliar nutrients and litter production have also included soil nutrient information. Thus the objective of the soil nutrient study is to document spatial and temporal variability of soil nutrients within the study area and determine if soil nutrients are independent of ELF field exposure, there by determining the suitability of soil nutrients for inclusion in covariate analysis and modeling.

Sampling and Data Collection

Soil nutrient samples are collected monthly during the growing season. During the 1987 growing season sampling began in May and concluded in October at the ground, antenna and control sites. In 1986, sampling began in June and concluded in September. However, in 1985 the hardwoods were sampled monthly, while the plantations were sampled only once in July. After initial success in using soil nutrients in the hardwood growth models, it was decided that sampling in the plantations would also be conducted monthly in successive years to provide soil nutrient data for the red pine growth analysis. Twenty randomly selected samples per plot were collected using a push probe inserted to a depth of 15 cm into the mineral soil. Samples were then composited to 5 per plot, dried in a convection oven at 60 degrees Celsius, and analyzed for Kjeldahl N, total P, and exchangeable Ca, Mg, and K.

Progress

Average monthly nutrient content values were generally greater in the hardwood stands at the control than at the antenna site for nearly all sampling dates in 1985-87 (Table 10, Appendix B). In addition, the 1985 values are higher than in 1986 and 1987 for both the hardwood stands and the plantations (Table 11, Appendix B). There is a general decline in all soil nutrients except N from 1985 to 1987. N increased from 1986 to 1987 at all sites.

Hardwood Stands

Analysis of variance was conducted to test differences in soil nutrient content (Kg/ha) for sites, years, and months for the hardwood stands (Table 1.22). Results varied depending upon the nutrient and factor tested but in general,

significance levels were higher for sites than for years.

Table 1.22. Significance levels from the analysis of soil nutrient content, 1985-1987.

	HARDWOODS[c]				
	Ca	Mg	K	P[b]	N
Site	.018	.033	.006	.686	.281
Year	.000	.000	.000	.000	.000
Site by year	.058	.342	.120	.006	.009
Month	.018	.809	.000	.025	.000
Month by site	.090	.184	.831	.106	.000
Month by site by year	.003	.267	.351	.226	.003

	PLANTATIONS[a]				
	Ca	Mg	K	P[b]	N
Site	.039	.121	.069	.720	.206
Year	.365	.010	.017	.000	.000
Site by year	.070	.098	.221	.183	.254
Month	.002	.033	.011	.001	.000
Month by site	.980	.424	.096	.096	.000
Month by site by year	.089	.063	.337	.484	.000

[a] Plantations were sampled in July only in 1985, therefore analysis was conducted on June through September 1986-87 data.

[b] ANOVA for P was conducted on 1986 and 1987 data only due to differences in laboratory methods between 1985 and following years.

[c] ANOVA for hardwood stands was conducted on the months of June through September 1985-1987.

Potassium was used as a covariate in the hardwood productivity studies and has been the most important soil nutrient in terms of explaining growth differences between sites and years. Significant differences (p=0.05) were found for potassium and calcium for sites, years, and month factors (Table 1.22).

Annual Comparisons: ANOVA tests showed that all

nutrients were significantly different among years. The Ca, Mg, and K contents have declined during the three year study (Table 1.23). Phosphorus, which could only be compared for 1986 and 1987, also exhibited a significant decrease in P content. Nitrogen shows an oscillating pattern with lowest values being found in 1986. We will be examining these nutrient values more closely as such large yearly variations are not expected and may be due to sampling error (Table 1.23).

Table 1.23 Soil means (Kg/ha) by year for hardwoods (85-87).

	Exchangable Nutrient			Total	
Year	Ca	Mg	K	P	N
1985	569.78[a]	72.11[d]	70.53[f]	-	1226.24[j]
1986	312.48[b]	70.19[d]	48.26[g]	1043.72[h]	623.29[k]
1987	279.77[c]	46.61[e]	49.20[g]	666.51[i]	1088.47[l]

Values for a given nutrient with the same letter not significantly different at p=.05.

Site by Year Interactions: Comparisons between the control and the antenna showed that nutrient contents at both sites followed the same basic trends (Table 1.24). Nitrogen was the only nutrient that exhibited a significant difference in site by year for the three year study. Nitrogen decreases from 1985 to 1986 and increases from 1986 to 1987 (Table 1.25). This trend is apparent at both the control and antenna but the difference between sites decreases noticeably in 1987 compared to prior years (Table 1.24). The difference between sites was 72.08 Kg/ha and 196.17 Kg/ha for 1985 and 1986, respectively. However, in 1987 there was only a difference of 9 Kg/ha. Further research needs to be conducted to determine the cause of the decrease in site difference and whether this trend will continue. P was also significantly different for site by year interactions but there are only two years of comparable data due to differing lab techniques among 1985 and following years. Additional years must be included to ascertain whether ELF exposure has an effect on this nutrient. At this time there is no evidence to indicate that ELF affected the nutrients measured within the hardwood stands. Yearly differences in deposition of nutrients may account for the some of the difference between years.

Table 1.24. Soil exchangeable Ca, Mg, K means by site and year for the hardwood stands.

Site	Year 1985	1986	1987
	Kg/ha		
Ca			
Control	675.58	377.47	373.28
Antenna	463.97	247.49	186.28
Mg			
Control	83.89	92.39	56.49
Antenna	60.32	48.00	36.74
K			
Control	80.66	53.24	54.74
Antenna	60.41	43.28	43.66

Red Pine Plantations

July was the only month in 1985 in which sampling was conducted on the red pine plantations. As a result, only soil nutrient data from 1986 and 1987 were used in the analysis of variance. Significant site differences ($p=0.05$) were found for calcium only while significant year differences exist for

Table 1.25 Site by year interactions for total nitrogengen in hardwood stands.

Site	Year 1985	1986	1987
	------Kg/ha-----		
Control	1262.28[a]	721.37[c]	1092.97[b]
Antenna	1190.20[b]	525.20[d]	1083.97[b]

Values with the same letter not significantly different.

all nutrients except calcium (Table 1.22). In addition, all site by year interactions were not significant for all nutrients. Significant differences exist between months for all nutrients. The plantations exhibit trends similar to the hardwood stands (Table 11, Appendix B). The seasonal variability of atmospheric nutrient deposition may help to explain monthly differences. Potassium has also been an important covariate in the red pine growth analysis which may be explained by the significant differences that exist in months and years. Significant differences between months were found for all nutrients.

Site by year interaction: There were no significant differences in site by year interactions for the plantations (Table 1.22). This showed that there is no significant difference between test sites exposed to electromagnetic magnetic fields and the control thus there is no evidence to indicate that ELF affected the nutrient content within the plantations.

Future work will focus on determining the effects of nutrient deposition from precipitation and other climatic factors on spatial and temporal variability in soil nutrient levels.

Element 2. Tree Productivity

Tree growth is sensitive to a variety of environmental disturbances. In order to detect any changes in growth due to treatment, accurate tree measurements are essential. The most widely accepted tree growth measurements are diameter at breast height outside bark (dbh) and height. Of these two growth variables, height is the more difficult to measure on mature trees. The installation of permanent dendrometer bands on the stem of a tree allows measurement of minute changes (0.008 cm) in diameter over a short time interval (Husch *et al.* 1982). Two additional advantages of using dbh as a measurement of tree growth are the responsiveness of cambial activity to environmental effects (Smith 1986) and the strong correlation between dbh and total biomass of the tree (Crow 1978). Consequently, measurement of diameter increment is the primary response variable for assessing the effects of ELF fields on hardwood stand growth. Tree height was used for initial stand characterization.

While dbh and height measurements can provide information on present stand production and a means to predict future productivity, the capacity of a stand to continue producing is also examined by monitoring tree reproduction and mortality. Stand structure (the distribution of trees by diameter classes) changes from year to year due to natural growth, reproduction, and mortality of trees. Any environmental disturbance could produce an effect on these factors. Therefore, to achieve a complete picture of possible ELF effects on tree and stand production, dbh, height, ingrowth, and mortality are being measured in order to distinguish natural changes from those caused by site disturbances.

In addition to tree productivity in hardwood stands, regeneration studies involving planted red pine seedlings are being conducted on the ground, antenna, and control sites. These studies were initiated in response to a need for a larger number of conifers in the ectomycorrhizal studies (Element 6) as well as to address the Michigan DNR concerns about forest regeneration. Since young trees often exhibit rapid growth rates compared to older trees, possible ELF field effects may be more easily detected on seedlings rather than on older trees. In the red pine seedlings, both diameter and height increment are response variables for assessing any possible effects due to ELF fields. Again, as in the case of trees in the hardwood stands, diameter, height, and mortality are being measured.

Hardwoods

Diameter increment is the primary response variable for assessing effects of ELF fields on the hardwood stands located on the antenna and control sites. Permanently installed

dendrometer bands allow continual measurements of incremental growth on each tree in the stand. This information provides a view of both the total growth in an entire growing season and the rate or distribution of diameter growth over the growing season.

Hardwood stands on both study sites are classified in the Acer-Quercus-Vaccinium habitat type (Coffman *et al.* 1983). Those species common to both sites and included in the analysis are northern red oak (*Quercus rubra*), paper birch (*Betula papyrifera*), bigtooth aspen (*Populus grandidentata*), quaking aspen (*Populus tremuloides*), and red maple (*Acer rubrum*). A summary of stand information for both sites can be found in Table 2.1; the change in average dbh on the study sites for each year since 1984 is given in Table 2.2.

Each analysis will eventually test the overall null hypothesis:

> H_0: There is no difference in the magnitude or the pattern of seasonal diameter growth before and after the ELF antenna becomes operational.

This hypothesis is addressed through testing of differences between the control and the antenna sites and testing for differences between post-operational years and previous years. The system operated at low levels throughout the growing season during 1987 (15 amps) and 1988 (75 amps). Whenever possible, differences between sites and between 1987, 1988, and previous years are examined. Tests concerning the rate or the distribution of diameter growth are made using the diameter growth model discussed later in this section. Differences in the parameters of the growth model between years and sites will also be examined to test the above hypothesis. This test for differences in growth model parameters indicates whether or not different seasonal growth patterns are occurring on the different sites. Differences in the magnitude or amount of seasonal diameter growth are examined through the split plot analysis of covariance. The analysis of covariance table used in this study is found in Table 2.3. Since monthly soil nutrient concentrations are a critical covariate, the analysis of covariance reported here is performed on data through 1987. An analysis including the 1988 data will be performed following the completion of laboratory analyses of the soil samples.

Sampling and Data Collection

To monitor diameter growth on both sites, permanent dendrometer bands were installed in 1984 on all trees greater than or equal to 10 cm dbh. Due to vandalism, 175 new bands were installed on the control site in 1985. On the antenna site the number of study trees was reduced from 209 in 1984 to 197 in 1985 due to a few band failures and a small vandalism incident unrelated to that on the control site. The death of one bigtooth aspen on the control site reduced that sample to 274 trees in 1985. At the start of the 1987 growing season, the trees which had band failures and suffered vandalism in

Table 2.1. Summary of hardwood stand information for the antenna and control sites at the beginning of the 1988 growing season.

Species	Average DBH (cm)[b/]	Basal Area Per Hectare (m^2/ha)	Number Bands in 86	Number Bands in 88[c/]	Number of Stems per Hectare	Site Index	Age (yrs)
Antenna							
Northern Red Oak	24.61	7.50	44	49	156	68	49
Paper Birch	20.83	0.93	8	8	25	66	57
Aspen[a/]	26.20	2.67	15	15	48	68	52
Red Maple	15.88	8.93	129	148	470	56	44
Control							
Northern Red Oak	21.58	21.69	174	175	556	72	54
Paper Birch	17.06	2.86	40	40	127	60	56
Aspen	23.47	5.94	44	43	137	65	57
Red Maple	11.65	0.62	15	22	70	58	47

[a/] The two aspen species are combined.

[b/] Average DBH includes ingrowth trees for 1987 but not trees which died in 1988.

[c/] Includes trees wnich grew to larger than 10.0 cm dbh since 1985 which were banded in 1987 but not trees which died in 1988.

Table 2.2. Average dbh (cm) by species and site at the beginning of each year of this study.[a/]

	1984	1985	1986	1987	1988	1989[b/]
Antenna						
Northern Red Oak	22.18	22.45	22.69	23.09	23.36	23.76
Paper Birch	20.02	20.22	20.42	20.56	20.70	20.83
Aspen[c/]	24.59	25.01	25.37	25.67	25.93	26.20
Red Maple	14.87	15.09	15.23	15.33	15.44	15.89
Control						
Northern Red Oak	20.45	20.62	20.82	20.94	21.12	21.58
Paper Birch	16.12	16.23	16.30	16.36	16.41	17.21
Aspen	22.21	22.55	22.82	23.03	23.18	23.47
Red Maple	11.37	11.64	11.85	12.01	12.17	12.28

A/ Only trees banded prior to 1987 are represented here.

B/ Values given for the beginning of the 1989 growing season were calculated by adding all previous years growth to diameter taken in 1984.

C/ The two aspen species are combined.

Table 2.3. ANOVA table used for analysis of diameter growth by species.

Source of Variation					
Covariate	Group (A)	# group A covariates	SSC	MSC	MSC/MSE(S)
Site		1	SSS	MSS	MSS/MSE(S)
Error(S)		# trees-2-#covariates	SSE(S)	MSE(S)	
Years		# years-1	SSY	MSY	MSY/MSE(SY)
Site x Years		(1)(#years-1)	SSSY	MSSY	MSSY/MSE(SY)
Covariate	Group (B)	# group B covariates	SSCY	MSCY	MSCY/MSE(SY)
Error(SY)		(#trees-2-#covariates)(#yrs-1)	SSE(SY)	MSE(SY)	

Group A covariates differ by site but not by year, such as soil characteristics.
Group B covariates change from year to year, such as annual rainfall.

1985 on the antenna site, as well as all trees which had become larger than 10 cm in dbh since 1984, were banded on both sites (Table 2.1). In 1988, there were four trees on the control site (a northern red oak, two paper birch, and one bigtooth aspen) which died. This mortality in 1988 occurred on trees which had not grown appreciably since the study started (Table 2.4), indicating they were not very vigorous, and they probably succumbed to climatic stress during the 1988 growing season. This gave a total of 213 banded trees on the antenna site and 273 banded trees on the control site.

Bands were read to the nearest 0.01 inches of circumference at both study sites beginning on April 13 in an attempt to insure monitoring of diameter growth initiation. Weekly readings continued until October 5 when growth had slowed considerably and over 50 percent of leaf fall had taken place. This provided a total of 25 measurements in 1988.

Progress

Growth Analysis

Magnitudes and rates of diameter increment were examined for each species. Analysis of tree diameter is approached in two ways. The split plot analysis of covariance is used to determine if there is any change in the magnitude of average yearly diameter growth due to ELF fields. Secondly, regression models are being developed to further quantify the relationships between tree, site, and climatic variables and tree diameter growth. These models are used to test for changes in both seasonal growth pattern within a year and relationships affecting total annual growth due to ELF fields. The modeling analyses use information for trees banded since 1985. The split plot analysis of covariance only utilizes growth information on trees which have been banded for the entire study period.

Analysis of Total Seasonal Diameter Growth

At present, five years (1984 through 1988) of diameter increment data have been collected from trees on the study sites. In 1984, first incremental growth was not collected until early June due to a relocation of the control site. Because of this, total diameter increment in 1984 is not derived from dendrometer band data, but from spring and fall diameter tape measurements of individual trees. Also, due to installation and calibration of the ambient monitoring equipment, the climatic variables are not completely available for 1984. For these reasons, the 1984 diameter growth measurements were not included in the split plot analysis of covariance. As suspected during the analysis in previous years (Mroz *et al.* 1987), monthly soil nutrient concentrations

Table 2.4. Growth history (1984-1987) of the trees which died at the control site in 1988.

Tree Number	Species	Diameter at Beginning of 1984 (cm)	Diameter Growth (cm) 1984	1985	1986	1987
321 127	NRO[a/]	12.8	.00	.01	.01	.00
321 203	PB	10.0	.00	.01	.01	.00
323 309	BTA	16.4	.00	.01	.06	.00
323 206	PB	12.5	.00	.00	.01	.06

[a/] NRO = Northern Red Oak
PB = Paper Birch
BTA = Bigtooth Aspen

proved to be an important covariate for explaining both site and yearly differences in diameter growth. These data are not yet available for the complete 1988 growing season; the tree growth information from 1988 will not be incorporated into these analyses until a complete set of covariates is available. Table 2.5 presents the total annual diameter growth by species for each of the five growing seasons, even though data from 1984 and 1988 are not included in the following analyses.

Analysis of annual diameter growth on the study plots began with an intensive variable screening procedure to select covariates to include in the split plot analysis of covariance. The physical and environmental variables measured in this study are available only on a plot or site basis, not for individual trees, and may or may not vary across years. To reduce confusion due to within plot variation in growth, the average annual diameter growth on a plot for a given year was used as the dependent variable during the initial variable screening procedures rather than the diameter growth of individual trees. During the analysis of covariance discussed below, individual tree diameter growth was the dependent variable.

During initial correlation analyses, the expected high degree of multicollinearity between related measurements was realized. In temperature related measurements, for example, soil temperatures at 5 and 10 cm depths and air temperature at 2 m aboveground were available for each plot. Degree days (4.4° C basis) were calculated for the entire growing season and to various points (monthly) within the growing season. Species' average growth rates are generally correlated with all of these variables which in turn are all correlated with each other. Similar relationships were found between the soil nutrient variables. During further analysis, it was sometimes found that the variable having the highest correlation with plot average diameter growth did not perform as well in the analysis of covariance when considered simultaneously with other environmental variables. In the discussion below, emphasis is on those variables which performed well in the split plot analysis of covariance and which showed high correlations, as compared to similar variables, with diameter growth.

Fuller *et al.* (1987) found that cumulative air temperature degree days was the dominant variable affecting the pattern of seasonal growth for each species on the study sites. Seasonal cumulative air temperature degree days was also the temperature variable which contributed most to the split plot analysis of covariance for northern red oak, paper birch, and aspen. It was not the temperature variable most highly correlated with average plot diameter growth for any of these three species (Table 2.6). Soil temperature degree days at 5 cm to some point in the growing season was the most highly correlated temperature variable for northern red oak and aspen. Soil temperature degree days is probably more strongly related to soil nutrient concentration and thus added

Table 2.5. Average seasonal diameter growth (cm) for tree species on each site for the 1984, 1985, 1986, 1987, and 1988 growing seasons.[A/]

	Sample Size	1984	1985	1986	1987	1988
		cm				
Northern Red Oak						
Antenna	44	0.2778	0.2389	0.1991	0.2710	0.2354
Control	174	0.1707	0.2030	0.1508	0.1823	0.1595
Paper Birch						
Antenna	8	0.2000	0.2038	0.1500	0.1304	0.1132
Control	40	0.1050	0.0765	0.0652	0.0406	0.0419
Aspen						
Antenna	15	0.4133	0.3653	0.2993	0.2355	0.2576
Control	44	0.3386	0.2643	0.2164	0.1529	0.1713
Red Maple						
Antenna	129	0.2163	0.1374	0.1017	0.1130	0.0830
Control	15	0.2667	0.2040	0.1533	0.1768	0.0690

[A/]Only trees banded prior to 1987 are represented here.

Table 2.6 Selected correlations between temperature variables and average plot diameter growth on the two study sites (combined).

Temperature Variable	Species			
	Northern Red Oak	Paper Birch	Aspen	Red Maple
Air Temperature Degree Days Through				
April	-	-.59	-	.63[a/]
May	-.48	-.79	-	.66*[b/]
August	-	-.61	-.82	-
September	-.22*	-.69*	-.86*	-
Soil Temperature Degree Days at 5 cm Through				
May	-.66	-	-	-
August	-	-	-.71	-
September	-.54	-.67	-.74	-
Soil Temperature Degree Days at 10 cm Through				
August	-	-	-.75	-

[a/] The critical correlation value ($p=0.05$) is $\pm .44$.
[b/] An * indicates the temperature variable which contributed most to the analysis of covariance, in conjunction with other variables, on individual tree diameter growth.

less to the split plot analysis of covariance than air temperature degree days. For red maple, air temperature degree days through May was the temperature variable most highly correlated with average plot diameter growth and was also the temperature variable which contributed most to the analysis of covariance.

Fuller *et al.* (1987) found that northern red oak begins growing sooner than the other species on the study sites and grows at a more constant rate throughout the year. Paper birch and aspen both initiate growth later than northern red oak and begin to slow growth earlier. Red maple begins growing at a later date than the other species but growth begins to slow at about the same time as aspen and paper birch. The fact that northern red oak begins growing early in the year probably explains why soil temperature early in the growing season is more highly correlated than air temperature with the growth of this species. For red maple, both the importance of air temperature early in the growing season and the positive relationship between temperature and growth are probably related to the timing of growth initiation. The negative relationships with temperature for paper birch and aspen agree with observations made by Holdaway and Brand (1985) in northern Minnesota and could be a result of the genetic makeup of the local populations. The local populations are probably more adapted to the cooler northerly climate of the study sites and may be responding to the stress of the increased respiration required by the higher temperatures. Such a response may not be apparent at these temperatures at more southerly sites or in regional studies of the effect of climate on diameter growth. The relationships given here should not be expected to hold over the entire geographical range of these species.

For every species except northern red oak, there was at least one significant ($p = 0.05$) correlation between a monthly level of at least one soil nutrient and average plot diameter growth (Table 2.7). For paper birch, aspen, and northern red oak, total Kjeldahl nitrogen in either June or July was the nutrient variable most highly correlated with average plot diameter growth. For aspen, a nearly identical correlation was observed for June calcium concentration as for July total Kjeldahl nitrogen. For all three species, however, potassium level in July was the nutrient variable which contributed most to explaining differences between sites and years in individual tree growth (see below). Mroz *et al.* (1987) showed that potassium concentration in the soil is significantly different ($p = 0.05$) between sites and years and that the potassium deposited by rainfall is significantly different between years. There were also significant differences in potassium in the litter for red maple and northern red oak in 1987 and potassium was the only nutrient which differed between sites in the green red oak foliage. For most years at the study sites, more degree days are accumulated in July than any other month; it is also the month where soil moisture tension is greatest (Mroz *et al.* 1987). Given the role of

Table 2.7. Selected correlations between soil monthly nutrient levels (upper 15 cm) and average plot diameter growth for the two study sites (combined).

Nutrient	Species			
	Northern Red Oak	Paper Birch	Aspen	Red Maple
Calcium Level in				
June	.23[a/]	-	.46	-
July	-	-	-	.55
Magnesium Level in				
June	.35	-	.35	-
Potassium Level in				
July	.01*[b/]	-.13	.22*	.66*
September	-	-.32	-	.57
Total Kjeldahl Nitrogen in				
June	.49	.51	.42	-
July	-	-	.47	-
September	-	-.42	-	-

[a/] The critical correlation value ($p=0.05$) is $\pm .44$.
[b/] An * indicates the nutrient variable which contributed most, in conjunction with other variables, to the analysis of covariance on individual tree diameter growth.

potassium in stomatal response and the fact that potassium deficiency can lead to a reduction in rates of photosynthesis and an increase in respiration rates (Kramer and Kozlowski 1979), an adequate potassium concentration in the soil at the time of maximum climatic stress may minimize the impact of this stress on growth. Klock *et al.* (1984) indicate that potassium concentrations from 20 to 100 ppm appear sufficient to meet tree requirements. Concentrations of potassium on the study sites tend to be near the low end of this range in July with a minimum of 16 ppm recorded on Plot 2 at the antenna site in July, 1986. For red maple, potassium level in July was the nutrient variable most highly correlated with average plot diameter growth. July potassium level was also the most important variable in the split plot analysis of covariance.

No significant relationships between diameter growth rates and either amount or timing of precipitation or soil moisture content at either 5 or 10 cm were found for any species on the study sites. One possible reason for this is that maximum soil moisture tension observed at each depth was approximately .3 -MPa with tensions greater than .2 -MPa being rare during the growing season from 1985 to 1987. The physical characteristic of water retention capacity was an important variable for paper birch and red maple (Table 2.8). Water retention capacity was less correlated with diameter growth for northern red oak and aspen and did not contribute to the split plot analysis of covariance for either species. Water retention capacity is a function of a number of soil properties, primarily texture, organic matter content, and bulk density. Since it is relatively constant over time and the annual moisture conditions are not significantly related to average annual diameter growth, this variable may be indicating other conditions in the rooting zone rather than the available moisture on the sites. In the analysis of covariance on individual tree diameter growth, water retention capacity from 10 to 30 cm was the most important moisture variable for paper birch while water retention capacity from 5 to 10 cm was most important for red maple. In mixed hardwood stands of red maple and red oak, Lyford and Wilson (1966) reported the litter layer to be dominated by red maple roots even though the major component of the stand was red oak. Similarly, Gale and Grigal (1987) indicate that more tolerant species, such as red maple, would be expected to have a greater proportion of their root system near the surface compared to intolerant species such as paper birch. This may explain why the soil water retention capacity at a greater depth was more significant in the split plot analysis of covariance for paper birch than for red maple and may explain why soil water retention capacity at depths less than 30 cm did not contribute in the analysis of covariance for proportionally deeper rooted species such as northern red oak and aspen.

An initial analysis of variance, without the use of covariates, was performed for each species. In all four species, there were highly significant ($p < 0.01$) differences

Table 2.8. Correlations between soil water retention capacity (cm/cm) and average plot diameter growth on the two study sites (combined).

Depth	Species			
	Northern Red Oak	Paper Birch	Aspen	Red Maple
0-5 cm	-.36[a/]	-.73	.17	.78*[b/]
10-30 cm	-.39	-.58	-	.66

[a/] The critical correlation value (p=0.05) is ±.44.
[b/] An * indicates the moisture variable which contributes the most, in conjunction with other variables, to the analysis of individual tree diameter growth. No moisture variable contributed to the analysis of covariance for northern red oak or aspen.

indicated in individual tree diameter growth rates between the two sites and among the three study years (Table 2.9). For northern red oak, there was a significant interaction between site and year. The covariates used were those indicated previously: seasonal total air temperature degree days and July soil potassium level for all four species with the addition of water retention capacity from 10 to 30 cm for paper birch, and water retention capacity from 5 to 10 cm for red maple. For all four species, the significant differences between sites and among years in individual tree diameter growth were accounted for by these covariates (Table 2.9).

The nonindependent relationships among the covariates were such that the variables having the greatest correlations with the dependent variable when considered separately did not perform as well in combination in the analysis of covariance as some variables which were less highly correlated when considered separately. This was particularly true in this analysis for the nutrient variables. While June or July soil nitrogen level was the nutrient variable most highly correlated with plot average diameter growth for all species except red maple, July soil potassium level performed better in the analysis of covariance on individual tree diameter growth. For aspen and paper birch, the use of nitrogen level for the appropriate month also explained a significant amount of the differences between sites and among years, but the use of July soil potassium level proved superior in that it explained an even greater amount of these differences.

For northern red oak, there was a significant interaction between sites and years in the analysis of covariance performed on the actual individual tree diamete growth rates. This interaction fell into the type described by Cox (1958) as "removable interactions"; the differences between sites were not constant over years even though one site had consistently greater individual tree diameter growth rates than the other. As suggested by Cox, a logarithmic transformation was applied to the individual tree diameter growth rates to give the results in Table 2.9. Using the same reasoning, even though there was not a significant interaction ($p = 0.05$), a logarithmic transformation also led to improved results in the analysis of covariance on red maple.

In summary, there were systematic differences between sites and years in individual tree diameter growth for all four species which were accounted for by the covariates. There was no detectable unexplained differences ($p = 0.05$) in individual tree diameter growth which might have been due to testing of the ELF antenna in 1987. Following completion of laboratory analysis, growth data from 1988 will be added to the analysis using the same set of covariates for each species.

Table 2.9. Significance levels[a/] for the analyses of variance and covariance of individual tree diameter growth.

Species	Source of Variation		
	Site	Year	Site*Year Interaction
Analysis of Variance (No Covariates)			
Northern Red Oak	.006	.000	.000
Paper Birch	.000	.000	.090
Aspen	.000	.000	.256
Red Maple	.000	.000	.410
Analysis of Covariance			
Northern Red Oak[b/]	.810	.064	.648
Paper Birch	.242	.820	.678
Aspen	.758	.914	.710
Red Maple	.480	.674	.801

[a/] A significance level less that 0.05 indicates a significant difference at p=0.05.

[b/] For northern red oak and red maple, a logarithmic transformation was performed on individual tree diameter growth prior to analysis.

Diameter Growth Model

Many of the relationships between diameter growth and tree, site, and climatic variables can be expected to be nonlinear (Spurr and Barnes 1980, Kimmins 1987). These nonlinear relationships cannot be adequately accounted for in the split plot analysis of covariance described above. In order to supplement the split plot analysis of covariance, diameter growth models for each of the four species are being developed to further account for variability in growth between sites and over years. Since the seasonal pattern of diameter growth as well as total annual growth could be subject to ELF field effects, the weekly cumulative diameter growth (cm) was selected as the response variable.

Differences in diameter growth observed since 1985 include differences in the timing of growth between sites, differences in timing of growth between species, and differences in the amount of growth between years (Mroz *et al.* 1986). Since the stand conditions did not change drastically since 1985, these observed diameter growth differences are likely due to differences between species, climatic differences between years, and physical differences between sites. By breaking cumulative diameter growth into the component parts of total annual growth and proportion of total growth completed by the date of observation, the effect of tree, site, or climatic variables on each of these diameter growth components can be examined. This also simplifies the testing for significant effects of ELF fields on tree diameter growth. Cumulative diameter growth to time t is therefore represented by:

$$CG_t = (\text{Total Annual Growth})(\text{Proportion of Growth to Time t})$$

This formulation allows the testing of ELF field effects on both the level of total annual growth (TAG) and the pattern of seasonal growth. In the model, total annual growth is further broken into the component parts of potential growth, the effect of intertree competition, and the effect of site physical, chemical, and climatic properties:

$$\begin{aligned} TAG = {} & (\text{Potential Growth})\ (\text{Intertree Competition}) \\ & (\text{Site Physical, Chemical, and Climatic Properties}) \end{aligned}$$

Each of these components, and the seasonal growth pattern component, are discussed below. Since many of the environmental variables, such as total seasonal air temperature degree days, have one value for a site in a year, it was not possible to fit the diameter growth model for each year for each site and compare the coefficients. The data from the three years were combined for each site to estimate the model; the coefficients of the resulting model were compared to evaluate site differences. If there were no site differences, the data from the two sites were combined to estimate an overall model for all sites and years for each

species. Year to year variation is being examined by examining the residuals (diameter growth predicted by the model minus the observed diameter growth for each tree) associated with the observations from each year on each site.

Potential Growth

In the above formulation, potential growth is defined as the amount of diameter growth that a tree could achieve if there are no environmental variables limiting growth. Results from previous years (Mroz *et al.* 1985, 1986) indicated that the model form given by Botkin *et al.* (1972) for representing potential growth showed the most promise on these study sites. A slightly modified form of this model is used to represent potential growth (PG):

$$PG = \frac{G\ D\ (1 - D/D_{MAX})}{274 + 3\ b_2\ D - 4\ b_3\ D^2}$$

where D is tree DBH, D_{MAX} is the maximum observed tree diameter for a species, and G, b_2, and b_3 are species specific constants. In order to constrain the model so that logical predictions are obtained when D is near D_{MAX}, the following relationships must hold for b_2 and b_3 (Botkin *et al.* 1972):

$$b_2 = 2\ (H_{MAX} - 137)/D_{MAX}$$

$$b_3 = (H_{MAX} - 137)/D_{MAX}^2$$

where H_{MAX} is the maximum tree height observed for a species.

Results from previous years (Mroz *et al.* 1985, 1986) indicated that the coefficients of the model required re-estimation. As discussed by Botkin *et al.* (1972) and Reed *et al.* (1988a), this is probably due to the fact that H_{MAX} and D_{MAX} are site specific within a species rather than constant for a species. Ek *et al.* (1984) give an expression relating total tree height to DBH, site index, and stand basal area for each of the four species in this study. Stand basal areas exceeding 32 m^2/ha can be achieved by mixed species northern hardwood stands, but they are relatively rare (Reed et. al. 1988b). Assuming a basal area of 32 m^2/ha, the equation given by Ek *et al.* (1984) can be manipulated to estimate D_{MAX} and H_{MAX} for each of the four species for any site if site index is known. This was done for both the antenna and control sites; the resulting estimates of D_{MAX} and H_{MAX} were then used to fit b_2 and b_3 according to the limiting relationships given above (Table 2.10).

When the coefficients from the full model were estimated, there were no significant (p=0.01) differences in the estimates of G between sites for any species. The estimates of G from the final coefficient estimation procedures are given in Table 2.11, together with the estimates of G given by

Table 2.10. Site specific estimates of D_{MAX} H_{MAX}, and the resulting estimates of b_2 and b_3, for the four species on the two study sites.

Species	Site	Site Index (m at age 50)	H_{MAX} (cm)	D_{MAX} (cm)	b_2	b_3
Northern Red Oak						
	Antenna	20.7	2359	72	61.722	.42863
	Control	22.0	2416	73	62.438	.42766
Aspen						
	Antenna	20.7	2324	61	71.705	.58775
	Control	19.8	2278	60	71.367	.59472
Paper Birch						
	Antenna	20.1	2287	60	71.667	.59722
	Control	18.3	2204	60	68.900	.57417
Red Maple						
	Antenna	17.1	2077	51	76.078	.74587
	Control	17.7	2105	52	75.692	.72781

Table 2.11. Estimated value of G from the study sites as compared with estimates given by Botkin et al. (1972) and Shugart and West (1977) for each species.

Species	Estimate of G	
	Previous Work	This Study
Northern Red Oak	62	200.78 (174.45, 227.10)[a/]
Paper Birch	140	139.23 (69.25, 209.22)
Aspen	140	112.92 (98.08, 127.76)
Red Maple	240	133.47 (117.63, 149.31)

[a/] Values in parenthesis give the asymptotic 95 percent confidence interval for the estimate of G from this study.

Botkin *et al.* (1972) and Shugart and West (1977). For paper birch and aspen, the values of G estimated in this study are not significantly different (p=0.01) from the estimates of G given by Botkin *et al.* (1972) and Shugart and West (1977). For northern red oak and red maple this is not the case. The estimates obtained in this study are significantly different (p=0.01) from those given in the previous work. Not only does there appear to be a need for site specific estimates of b_2 and b_3, it also appears that G is not constant for a species. The value of G incorporates various proportional relationships between total tree biomass increment, leaf area, and leaf biomass (Botkin *et al.* 1972), so it is not surprising that site specific values may be required since these relationships can vary by stand conditions as well as genetic makeup of the local population.

Intertree Competition

Results from prior years showed that residuals from the growth model were correlated with measures of competition for each tree (Mroz *et al.* 1986, 1987). Holmes (1988) evaluated the performance of numerous competition indices for use in the diameter growth model for each of the four species. Lorimer (1983) gave a simple competition index which performed best for northern red oak, red maple, and paper birch. This index is given by:

$$CI_i = \frac{D_j}{D_i}$$

where CI is the value of the competition index for the ith (subject) tree, D is the DBH of the respective tree, and the summation is over all trees within 7.62 m of the subject tree.

The mapped stand information was used to define which trees were competitors of each other. Since the plots are 30 m X 35 m, competitors could not be defined for all trees on the plots. There was no information concerning competitors outside the plots for those trees near the plot boundaries. For this reason, a 10 m buffer strip will be mapped around each study plot in 1989 and annual measurements of the diameters of all trees within the buffer will be added to the data base.

Holmes (1988) found that there were no significant differences in the correlation between Lorimer's competition index and diameter growth over sites and years (1985-1987) for northern red oak, red maple, and paper birch. A correlation of -0.64 was observed for northern red oak diameter growth and the competition index; the correlation was -0.75 for paper birch and -0.56 for red maple.

For aspen, the competition index given by Bella (1971) proved to be most highly related to observed diameter growth.

This index is given by:

$$CI_i = \Sigma [(a_{ij}/A_i) * (D_j/D_i)^3]$$

where CI_i is the value of the competition index for the ith (subject) tree, D is the diameter of the respective tree, A is the area of the influence zone for the respective tree, and a_{ij} is the area of influence zone overlap between the subject tree and the jth competitor. The summation is over all trees whose influence zone overlaps that of the subject tree. A tree's influence zone is defined as the area surrounding the tree which the tree's crown would cover in the absence of competition. This is defined as the open-grown crown radius and is calculated using relationships given by Ek (1974). The correlation between aspen diameter growth and the value of this competition index was -0.50.

Once a competition index was obtained for each tree, it was entered into the diameter growth model as described in a previous report (Mroz *et al.* 1987). A negative exponential relationship was assumed between diameter growth and increasing competition. In the model, this is represented by:

$$IC = e^{-(a * CI)}$$

where IC is the intertree competition component of the model, a is the coefficient to be estimated for each species, and CI is the value of the competition index for the respective tree.

Estimates of the value of the intertree competition coefficient (a) for each species are given in Table 2.12. For the all four species, there were no significant differences (p=0.05) between estimates of the coefficient between sites. Figure 2.1 illustrates the relative comparison of the effect of intertree competition levels on potential growth for northern red oak, paper birch, and red maple. Red maple, a tolerant species which can survive in low levels of sunlight, has a value of a which is significantly lower than northern red oak (p=0.05), indicating lesser growth reduction due to increased competition. Paper birch, which has a small sample size, is intermediate between red maple and northern red oak in the estimate of the competition coefficient (a) and is not significantly different from either species (p=0.05).

Site Physical, Chemical, and Climatic Factors

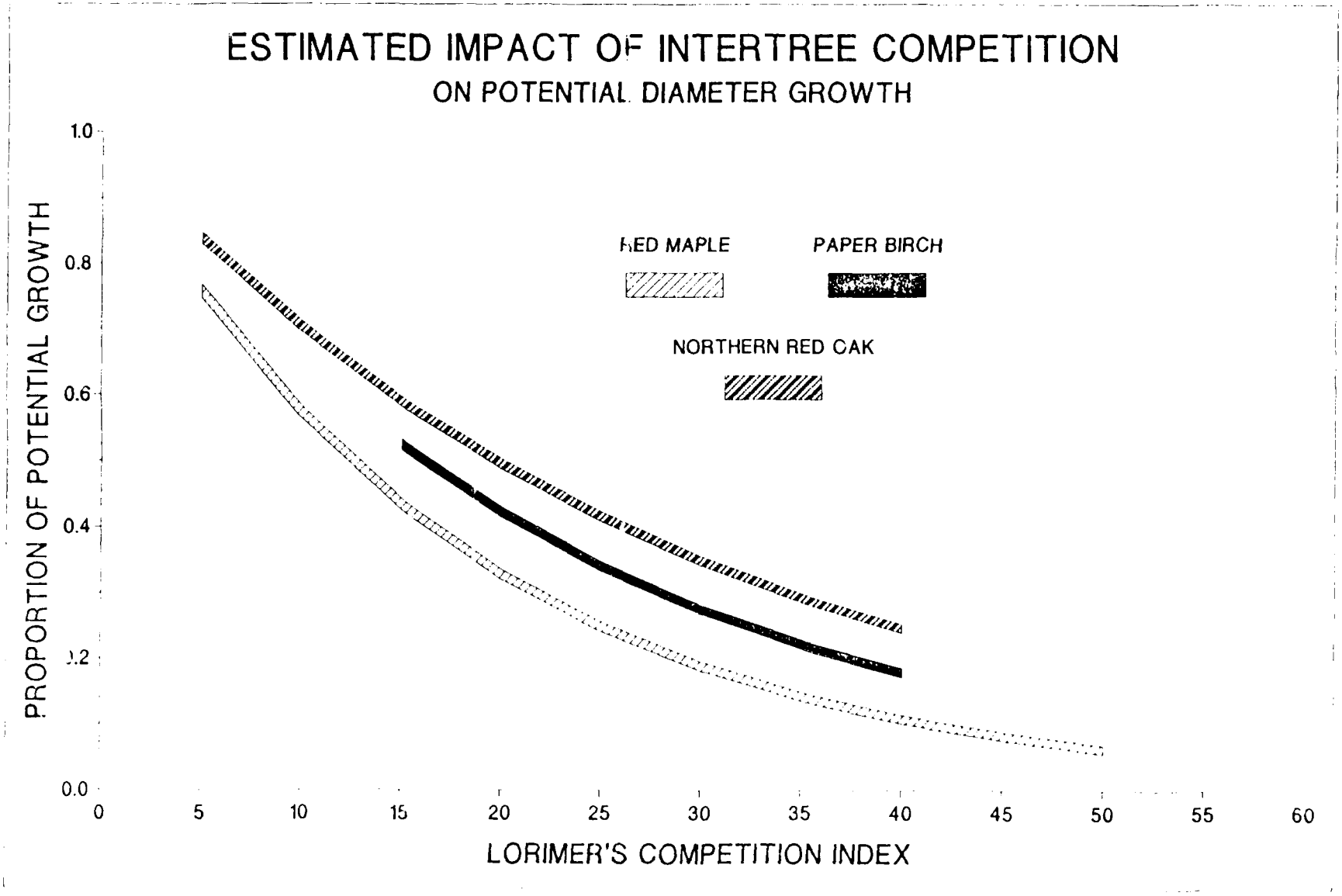
For environmental factors such as moisture, temperature, and soil nutrient levels, there is expected to be a range of values where a species responds positively to increased amounts of the factor, a range of values where the factor is adequate for the species and there is little response to increases or decreases, and a range of values where the species responds negatively to increased amounts (Spurr and Barnes 1980, Reed *et al.* 1988a). The variable screening procedure used to select covariates for the split plot

Table 2.12. Estimates and asymptotic 95 percent confidence intervals for a, the coefficient in the model component representing intertree competition.

Species	Estimate of a	Asymptotic 95 Percent Confidence Interval
Northern Red Oak	0.0557	0.0443, 0.0671
Paper Birch	0.0431	0.0150, 0.0712
Aspen [a/]	0.1206	0.0919, 0.1493
Red Maple	0.0352	0.0290, 0.0414

a/Bella's index is used for aspen; Lorimer's index is used for the other three species.

Figure 2.1.


ESTIMATED IMPACT OF INTERTREE COMPETITION
ON POTENTIAL DIAMETER GROWTH
PROPORTION OF POTENTIAL GROWTH
1.0
0.8
0.6
0.4
0.2
0.0
RED MAPLE
PAPER BIRCH
NORTHERN RED OAK
0
5
10
15
20
25
30
35
40
45
50
55
60
LORIMER'S COMPETITION INDEX

analysis of covariance which was discussed previously, identified environmental factors for each of the four species which were in the ranges where the species showed a response, either increased or decreased growth levels with changes in the level of the factor. The environmental factors identified for each species accounted for a large portion of the variation in diameter growth rates between study sites and among study years.

A component was added to the diameter growth model to represent the effect of site physical, chemical, and climatic factors on growth. Initially, the environmental factors identified as covariates in the split plot analysis of covariance were used in the diameter growth model. The environmental factors are accounted for in the model by a linear function which is constrained to produce the proportion of potential growth which might be expected:

$$SPCC = \frac{(D + b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3)}{D}$$

where SPCC is the effect of site physical, chemical, and climatic factors on diameter growth, D is tree DBH. The particular environmental factors (X_k) and the associated constants (b_k) are species specific. The factors identified as covariates in the split plot analysis of covariance were seasonal total air temperature degree days and July potassium level for all four species with the addition of water retention capacity from 10 to 30 cm in depth for paper birch, and water retention capacity from 5 to 10 cm in depth for red maple.

The estimated coefficients for the diameter growth model for each species are given in Table 2.13. For paper birch, the intercept (b_0 above) and the coefficient multiplied by July soil potassium concentration were not significant ($p=0.05$). There was no reduction in the proportion of total annual diameter growth accounted for by the model when they were deleted from the model; in fact, the proportion of variation accounted for by the model increased slightly when these terms were removed (0.724 versus 0.718). For northern red oak, the same two terms were also statistically nonsignificant ($p=0.05$) and the proportion of total annual diameter growth explained by the model was not greatly reduced when they were removed (0.443 versus 0.451) so they were deleted from the model. For aspen and red maple, all coefficients were statistically significant.

Seasonal Growth Pattern

Seasonal air temperature degree days to time t is the most important variable affecting the seasonal diameter growth pattern of all four species on both sites (Fuller *et al.* 1987, Mroz *et al.* 1986, 1987). The proportion of annual growth

Table 2.13. Estimated value and asymptotic 95 percent confidence interval for the coefficients of the site physical, chemical, and climatic factor model component for each species.

Species	Coefficient	Associated Variable	Estimate	95 Percent Confidence Interval	
Northern Red Oak	b_0	Intercept	-3.32	-12.75,	6.31
	b_1	ATD[a/]	-0.0045	-0.0056,	0.0034
	b_2	KJUL	0.1081	-0.0514,	0.2671
Paper Birch	b_1	ATD	-0.0025	-.0044,	-.0007
	b_3	WHC3	-37.26	-56.11,	-18.42
Aspen	b_0	Intercept	-47.28	35.02,	59.55
	b_1	KJUL	0.0356	-0.0429,	-0.0283
	b_2	KJUL	0.3456	0.1429,	0.5503
Red Maple	b_0	Intercept	-40.35	- 46.77,	-33.93
	b_1	ATD	0.0890	.0696,	.1084
	b_2	KJUL	0.1498	.0695,	.2302
	b_3	WHC1	12.71	6.47,	18.95

[a/]Notation:
ATD = Seasonal Total Air Temperature Degree Days
KJUL = Pottassium Concentration in Upper 15 cm of Soil (ppm)
WHC = Soil Water Retention Capacity 0-5 cm (cm/cm)
WHC3 = Soil Water Retention Capacity 10-30 cm (cm/cm)

expected in a given week is estimated using a difference form of a modified Chapman-Richards growth function and the cumulative air temperature degree days at the beginning and end of the week. This involves the implicit assumption that each species will respond to temperature up to a point and that further additions of degree days will not lead to increased growth.

Increased air temperature may lead to decreased levels of soil moisture due to increases in evaporation and plant respiration. The expected growth, given the cumulative air temperature degree days, may not be achieved if moisture is limiting. In the model, average soil water tension (-MPa) at a depth of 5 cm is used to indicate the moisture stress. Moisture is not assumed to be limiting if tension levels are below -.101 MPa (1 atm). Plant response is assumed to be a simple negative exponential function of increasing soil water tension.

The model combines the effects of cumulative air temperature degree days at the beginning (ATD_{t1}) and end (ATD_{t2}) of week t and average soil water tension at 5 cm in week t (SWT_t):

$$SGP_t = (e^{-(ATD_{t1}/b)^c} - e^{-(ATD_{t2}/b)^c})(e^{-d\,(SWT_t - .101)})$$

where SGP_t is the proportion of potential total annual growth expected in week t and b, c, and d are species specific coefficients to be estimated.

In the estimation process, all three of these coefficients were constrained to be greater than or equal to zero. Also, if the observed value of average soil water tension in a given week was less than -.101 MPa, then a value of -.101 MPa was used in the estimation procedure. The estimated values of the coefficients are given for each species in Table 2.14. For northern red oak and red maple, there were no differences in the estimated coefficients between sites. For paper birch and aspen, the value of d on the control site was estimated to be zero, probably due to small sample sizes and the fact that soil moisture tension was rarely above .101 -MPa on the control site (Figures 2.2 a and b). In this case, there was not enough information to estimate d on the control site and so the difference between sites could not be adequately evaluated statistically. There appeared to be insufficient evidence of differences between sites to justify separate analyses so the data from the two sites were combined to produce the estimates in Table 2.14.

Combined Model

The combined model, incorporating all four model components discussed above, was fit to data from all sites and years. This followed the evaluation of differences in coefficients between sites as discussed above for each model

Table 2.14. Estimated value and symptotic 95 percent confidence interval for the coefficients in the seasonal growth pattern model component for each species.

Species	Coefficient	Estimate	95 Percent Confidence Interval
Northern Red Oak	b	809.67	762.75, 856.60
	c	1.4351	1.3595, 1.5107
	d	-0.5125	-0.7882, -0.2367
Paper Birch	b	725.75	685.83, 765.68
	c	2.1470	2.1132, 2.7207
	d	-0.3278	-0.5708, -0.0849
Aspen	b	713.97	693.07, 734.87
	c	2.2878	2.1597, 2.4159
	d	0	- ---
Red Maple	b	761.11	740.05, 782.16
	c	2.1322	2.0256, 2.2388
	d	-0.5005	-0.7133, -0.2876

Figure 2.2 a.

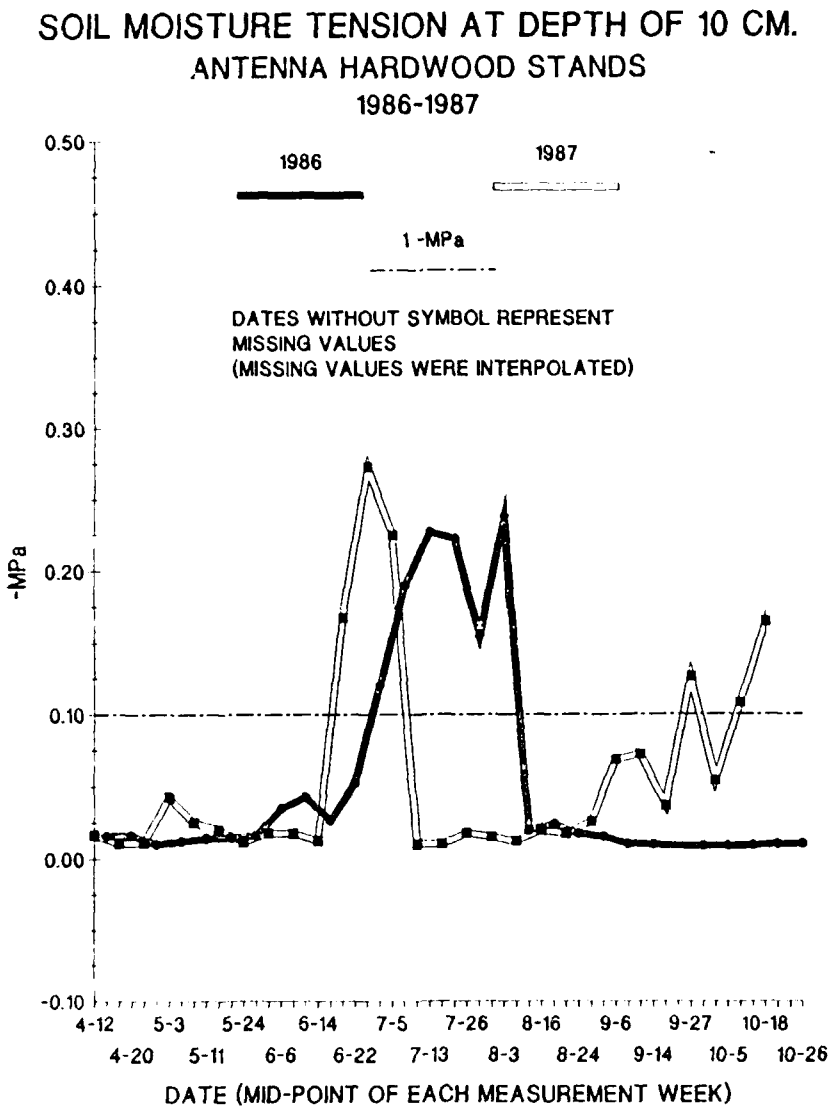
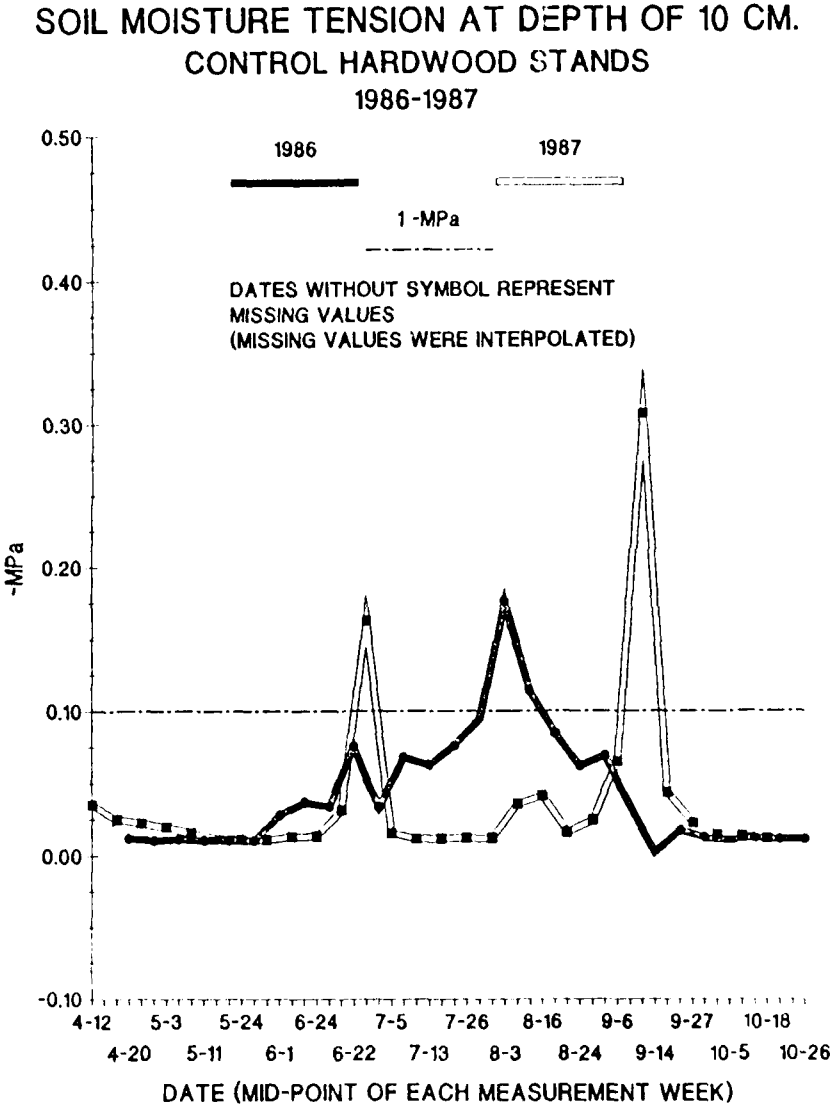


Figure 2.2 b.



component. Using the tree and climatic conditions occurring in the 1986 and 1987 growing seasons, predictions of total seasonal diameter growth were made for each tree and compared to the observed diameter growth values. Table 2.15 contains a summary of these comparisons. A studentized test on the average residual found no evidence of bias in the combined equation for any species except aspen. In other words, the average residual was not significantly different from zero ($p>0.10$) for northern red oak, paper birch, and red maple. For aspen, the average residual was significantly different ($p=0.01$) from zero, indicating a significant underprediction of observed growth by the combined model. Further work will attempt to improve the diameter growth model for aspen.

The standard error of the residual is analogous to mean squared error in ordinary least squares regression. In this case, not only was the regression nonlinear, but the evaluation in Table 2.15 is for estimates of total seasonal growth; analysis of the seasonal pattern of growth is continuing at this time. From Table 2.15, the standard error of the residuals is less than the measurement increment (0.008 cm using the dendrometer bands) for all species except aspen. This implies that the model prediction is within the measurement precision for those species.

The proportion of variation in total annual diameter growth is in the range found by other studies (Mroz *et al.* 1986, Harrison *et al.* 1986). Further improvement in these values may not be possible due to the precision of the field measurements and the rates of growth on the study sites as discussed above. With the exception of aspen, further work will concentrate on areas other than model refinement at this time.

Residual Analysis

Differences between the predicted total seasonal diameter growth and the observed values were examined by site and year for each species. If there is a change in the way a tree is responding to site or climatic conditions then the model will not perform as well. In other words, the differences between the observed and predicted diameter growth will increase if an additional factor is introduced which impacts tree growth. Residuals and studentized 95 percent confidence intervals for the mean residual are given by site and year for northern red oak in Table 2.16, for paper birch in Table 2.17, for aspen in Table 2.18, and for red maple in Table 2.19.

There was no case where the studentized confidence intervals from the different sites and years did not overlap for a species. For northern red oak, for example (Table 2.16), the confidence intervals from the antenna site in 1986 and 1987 and the control site in 1986 and 1987 all overlap in the range of 0.0041 to 0.0137 cm. This implies that to date there is no detectable difference in the performance of the model in predicting total seasonal diameter growth over the

Table 2.15. Summary of the combined diameter growth model performance for each species in predicting total seasonal diameter growth (sites and years combined).

Species	Number of Observations[a/]	Proportion of Variation Explained[b/]	Average Residual[c/] (cm)	Standard Error of Residuals (cm)	H_O: =0 H_A: ≠0
Northern Red Oak	165	0.443	0.0128 (6.42%)	0.0079	NS[d/]
Paper Birch	26	0.724	0.0037 (6.07%)	0.0075	NS
Aspen	81	0.286	0.0328 (16.89%)	0.0105	p=0.01
Red Maple	170	0.512	0.0010 0.97%)	0.0041	NS

[a/] Number of total growing season observations.

[b/] The proportion of variation explained by the model is calculated as:

$$\frac{\Sigma(y_i-\bar{y})^2 - \Sigma(y_i-\hat{y})^2}{\Sigma(y_i-\bar{y})^2}$$

[c/] The residuals are observed minus predicted values; a negative residual indicates an over prediction of diameter growth.

[d/] NS indicates a non-significant (p>0.1) studentized test of significance, for aspen, the studentized test indicated that there was significant (p=0.01) over prediction of average diameter growth by the model.

Table 2.16. Performance of the combined diameter growth model by site and year for northern red oak.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	20	0.0031	0.0254	-0.0501, 0.0563
	1987	22	0.0744	0.0388	0.0041, 0.1447
Control	1986	61	-0.0069	0.0103	-0.0275, 0.0137
	1987	62	0.0135	0.0112	-0.0089, 0.0359

Table 2.17. Performance of the combined diameter growth model by site and year for paper birch.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	3	0.0193	0.0241	-0.0844, 0.1230
	1987	3	-0.0045	0.0155	-0.0712, 0.0622
Control	1986	10	0.0047	0.0162	-0.0319, 0.0413
	1987	10	0.0007	0.0086	-0.0188, 0.0202

Table 2.18. Performance of the combined diameter growth model by site and year for aspen.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	11	0.0282	0.0193	-0.0148, 0.0712
	1987	11	0.0600	0.0227	0.0094, 0.1106
Control	1986	30	0.0533	0.0222	0.0079, 0.0987
	1987	29	0.0032	0.0133	-0.0240, 0.0304

Table 2.19. Performance of the combined diameter growth model by site and year for red maple.

Site	Year	Number of Observations	Average Residual (cm)	Standard Error of Residuals (cm)	Studentized 95% Confidence Interval
Antenna	1986	70	-0.0019	0.0059	-0.0137, 0.0099
	1987	80	0.0002	0.0064	-0.0126, 0.0130
Control	1986	10	0.0307	0.0143	-0.0016, 0.0630
	1987	10	0.0095	0.0129	-0.0197, 0.0387

sites or the years analyzed. This further implies that there is no detectable change in the total seasonal diameter growth on the antenna site following the testing of the antenna in 1987. There was an increase in the average residual value at the antenna site in 1987 (0.0744 cm) compared to 1986 (0.0031 cm). While there is no evidence at this time that this is due to the testing of the antenna, data from 1988 and later years will indicate if this pattern continues or if it is a single year aberration due to climatic conditions which may not be adequately represented in the model.

For the paper birch (Table 2.17), the studentized confidence intervals all overlap to a great degree and all incorporate zero, indicating unbiased model predictions for each site each year. The same is true for red maple (Table 2.19), even though the average residual for the control site in 1986 was larger than that for any other site/year combination. For aspen (Table 2.18), there was an increase in the average residual at the antenna site in 1987 (0.0600 cm) compared to 1986 (0.0282 cm). From the studentized confidence intervals, there is no indication that this is due to the testing of the antenna. The fact that the average residual at the control site in 1986 (0.0533 cm) was very similar to that at the antenna site in 1987, and much larger than that at the control site in 1986 (0.0032 cm) further indicates that there is no detectable impact on total seasonal diameter growth for aspen due to testing of the antenna in 1987.

Current work is concentrating on a similar analysis of residuals for the model component representing the timing of diameter growth during the growing season. When all of the variables in the model are available for the 1988 growing season, these data will be analyzed in similar fashion as described above for both total seasonal diameter growth and the timing of growth through the growing season.

Red Pine

Seedling Growth

Since young trees experience rapid growth rates, possible effects on growth due to ELF electromagnetic fields may be more easily detected on seedlings rather than on older more slowly growing individuals. Other justifications for investigating red pine seedlings are: 1) the response to Michigan DNR concerns over effects on forest regeneration, 2) the lack of sufficient natural conifer regeneration on the study sites for mycorrhizal studies, and 3) the magnetic fields associated with the antenna ground rapidly decrease over a short distance. Thus, construction of the antenna ground through a red pine plantation allows the study trees to be closer to the electromagnetic source than any mature tree plots which require a buffer strip of trees along the right-of-way.

Total height (cm) and basal diameter (cm) increment on the red pine seedlings are the response variables for assessing possible ELF electromagnetic field effects. Measurements made weekly (on seedling height only) and seasonally (seedling height and diameter) allow examination of both the total growth in a growing season as well as the distribution of growth within the season. This study is conducted on the ground, antenna, and control sites. A summary of stand information for the three study sites can be found in Table 2.20. Changes in average diameters and heights at each study site over the length of the study are found in Table 2.21.

The evaluation of red pine seedling growth is divided into two areas: 1) the determination of annual growth, vigor, and survival, and 2) the evaluation of seedling growth patterns as a function of time. The overall null hypotheses tested in this phase of the study are:

> H_o: There is no difference in the level of seasonal diameter growth of planted red pine seedlings before and after the ELF antenna becomes operational.

and

> H_o: There is no difference in the level or the pattern of seasonal height growth of planted red pine seedlings before and after the ELF antenna becomes operational.

As discussed earlier in the hardwood stand analyses, evaluation of possible ELF electromagnetic fields on height growth is approached in two forms: the level of height growth in a growing season is analyzed through the split plot analysis of covariance while the pattern of height growth within a growing season is described through a height growth model. Each of these analyses examines possible site differences as well as any existing differences between pre-operational and post-operational years. The analysis of covariance table used is the same as that found in the hardwood studies (Table 2.3). The level of diameter growth in a growing season will only be analyzed through the split plot anlysis of covariance.

Sampling and Data Collection

Small areas at the antenna, ground, and control sites were whole-tree harvested in June of 1984. These areas were immediately planted with 3-0 stock red pine seedlings at a 1 m by 1 m spacing. This density provided adequate numbers of seedlings for destructive sampling throughout the study period, allowed for natural mortality, and will leave a fully stocked stand when the study is completed. Following planting, 300 seedlings at each site were randomly selected and permanently marked for survival and growth studies. Additional details concerning the establishment of the red pine plantations can be found in past reports (Mroz *et al.* 1985, 1986).

Table 2.20. Summary of red pine stand information for the ground, antenna, and control sites at the end of the 1988 growing season.

Site	Sample Size	Average DBH (cm)	Average Height (cm)	Average Bud Size (mm)
Ground	137	2.43	90.22	22.40
Antenna	164	2.79	100.77	24.80
Control	192	2.71	116.69	24.16

Table 2.21. Average diameter (cm) and height (cm) for each site at the end of each year of this study.

	Sample Size	Diameter (cm)	Height (cm)
Ground			
1984	300	0.450	17.18
1985	170	0.743	22.73
1986	147	1.280	37.33
1987	141	1.880	59.19
1988	137	2.427	90.22
Antenna			
1984	300	0.441	16.80
1985	188	0.701	23.92
1986	184	1.262	40.34
1987	177	2.117	66.55
1988	164	2.794	100.77
Control			
1984	300	0.459	18.96
1985	217	0.792	28.33
1986	211	1.355	50.50
1987	199	2.116	69.85
1988	192	2.706	116.69

Natural mortality following the first full growing season (1985) was 43 percent at the ground site, 37 percent at the antenna site, and 28 percent at the control site. This mortality was somewhat high due to the late planting date which resulted in planting shock as well as desiccation of seedlings during handling and planting. In addition, Mroz *et al.* (1988) observed that 61 percent of the apparently healthy seedlings that did not form terminal buds following planting died, which further indicates the inability of some seedlings to adapt to the planting site. Precipitation during 1985 was adequate for seedling establishment and competition around each seedling was minimal. It is unlikely that these environmental factors had a significant effect in causing this mortality.

The mortality that occurred in 1985 was not evident in 1986, 1987, or 1988. Only a few seedlings died during the course of the last three growing seasons. In 1985 the number of permanently marked seedlings was reduced from 300 to 170 at the ground site, 188 at the antenna site, and 217 at the control site. In 1986, these numbers were further reduced to 147 seedlings, 184 seedlings, and 211 seedlings, respectively. Mortality during the 1987 field season resulted in a drop in samples to 141 seedlings at the ground site, 177 seedlings at the antenna site, and 199 seedlings at the control site. In 1988 there are now 137, 164, and 192 seedlings at the ground, antenna, and control sites respectively (Table 2.21).

Vegetation recovered following whole-tree harvesting especially in 1986. This vegetation competed with the red pine seedlings for physical resources such as moisture, nutrients, and light. Vegetation control was necessary in 1986 to prevent the competing vegetation from affecting the unrestricted growth of the seedlings. In early June of 1986, competing vegetation was mechanically removed from each plantation plot using gas powered weed-eaters equipped with brush blades. This method was successful in releasing overtopped seedlings and essentially eliminating competition in 1986. Early in the growing seasons of 1987 and 1988, we found that it was not necessary to repeat weed control again.

For red pine growth analyses, each of the live permanently marked seedlings on each site was measured at the end of the growing seasons in 1984, 1985, 1986, 1987, and 1988, and the following information recorded:

basal diameter (cm)
total height (cm)
terminal bud length (mm)
microsite
physical damage
presence of multiple leaders
number of neighboring seedlings

Information on microsite, physical damage, multiple leadered seedlings, and the number of neighboring seedlings was collected for possible use in explaining results of the growth analyses. Microsite described the physical environment in the immediate vicinity of the seedling such as rocky soil surface

or proximity to a stump or skid trails. In 1988 this measurement also included whether the seedling was located in a frost pocket or not. This was based on a visual determination of the surrounding topography. Any physical damage to a seedling such as frost or animal damage was also recorded. Some seedlings possess two or more leaders, none of which expressed dominance over the others, and this situation was noted as well. In addition, beginning in 1987, the number of seedlings surviving in neighboring planting spacings was also recorded to aid in describing any future competition for light and moisture between neighboring seedlings that might occur.

To further describe the growth of the red pine seedlings, a subsample of 100 seedlings per site was selected from the permanently marked seedlings for weekly height growth measurements. These weekly mearurements were obtained in 1985, 1986, 1987, and 1988. Measurements began in mid-April while shoots are still dormant and continued until mid-July when shoot elongation was completed. Measurements (to the nearest 1 mm) were made from the meristematic tip or the tip of the new terminal bud to the center of the whorl of lateral branches.

Progress

Growth Analysis

The two response variables in this segment of the study are height and diameter increment of red pine seedlings. Differences in total seasonal height or diameter increment from site to site or from year to year are analysed through the split plot analysis of covariance where tree, soil physical and chemical properties, and climatological data are used as covariates. The pattern of height growth in terms of the elongation of the leading shoot during the growing season is depicted through a growth model. This model has been developed to describe height increment only. The coefficients of this growth model are compared from site to site and from year to year to examine possible differences in the rate at which shoot elongation is achieved each year at each site.

Total Annual Height and Diameter Growth

Covariate Selection

Separate split plot analyses of covariance examine any existing differences in either seasonal height or diameter increment among the three sites as well as from year to year. At this point there are four years of growth measurements available (1985, 1986, 1987, and 1988). Previous analyses have indicated the importance of soil nutrient concentrations

as covariates to explain both site and yearly differences that occur in the height and diameter growth (Mroz *et al.* 1986). Because these data are unavailable for the 1988 growing season at this point, all analyses discussed include growth data from 1985, 1986, and 1987 only. The average seasonal growth for each of these response variables on each site at the end of each growing season (1988 included) are found in Table 2.2?.

Selection of covariates for the split plot analyses was conducted in the same manner as described in the hardwood studies. Correlations were calculated between tree, soil physical and chemical properties, and climatic data. Because physical and environmental data are collected on a plot or a site basis, average annual height or diameter growth on a plot was used as the dependent variable when determining correlations. This dependent variable was used rather than the individual tree height or diameter growth to reduce confusion due to within plot variation in growth as mentioned in the hardwood studies. For a given year's height or diameter growth, both the current seasonal site physical and chemical and climatic data as well as the previous year's seasonal site physical and chemical and climatic data were considered in the correlation analyses. Because climatic data was not collected in 1984, the correlation matrix for growth with the previous year's seasonal data includes only 1986 and 1987 growth combined with 1985 and 1986 site physical and chemical and climatic data, respectively. The correlation matrix of growth with current seasonal data examines 1985, 1986, and 1987 data.

Variables having high correlations with either height or diameter growth were considered for use as covariates in the split plot analysis of covariance. Generally, similar climatic variables (such as air temperature degree days (4.4° C) and soil temperature degree days (4.4° C) at 5 and 10 cm) had similar correlations with height and diameter growth, but were also highly correlated with each other as well. This was also true for site physical and chemical variables as well. Recognizing the high degree of multicollinearity that exists among similar variables, only a single variable from a group of similar variables was selected for use as a covariate to insure as much independence as possible. This selected variable was not necessarily the one with the highest correlation; the selected variable had a high correlation with growth, but also explained more of the existing differences in either height or diameter growth than the other variables with high correlations.

Annual Height Growth

Use of the previous year's site physical and chemical and climatic data explained more site and yearly variation than the current year's data when analyzing annual height growth in the split plot design. For this reason only height growth occurring in 1986 and 1987 together with 1985 and 1986 soil

Table 2.22. Average seasonal diameter growth (cm) and height growth (cm) for each site for the 1985, 1986, and 1987 growing seasons.

	1985	1986	1987
Diameter Growth (cm)			
Ground	0.27	0.53	0.60
Antenna	0.23	0.55	0.86
Control	0.32	0.57	0.76
Height Growth (cm)			
Ground	5.08	14.28	23.75
Antenna	6.61	16.06	26.96
Control	8.34	22.34	31.87

physical and chemical properties and climatic data are included in this particular analysis. The use of the previous year's soil physical and chemical properties and climatic data provides results that are consistent with the fact that red pine is a species of deterministic growth. Height growth in any year is strongly related to the size of the terminal bud which was formed under the previous year's site physical and chemical and climatic conditions (Kozlowski *et al.* 1973).

Prior to analyses of covariance, an analysis of variance (no covariates included) was performed and highly significant differences were found among the three sites and between the two study years ($p<.001$). No significant interaction was found between the study sites and years ($p=.05$). The average maximum air temperature for the month of June, total Kjeldahl nitrogen in the soil during July, and water holding capacity from 10 to 30 cm in the soil were the three covariates used in the analysis of covariance. These three covariates were able to explain all existing site and yearly differences ($p=.05$) (Table 2.23) indicating that there is no evidence of an effect of ELF fields on seedling height during the 1986 and 1987 growing seasons, a period of low level antenna testing.

Previous year's average maximum air temperature during the month of June was the temperature variable which contributed the most to the split plot analysis of covariance. It was also the most highly correlated variable with average plot height growth. Height growth (shoot elongation) during the current growing season begins in mid-April and ends around the middle to the end of July. The terminal bud (which affects the next season's height growth) is formed during the first or second week in June and continues growing into late September or early October. The timing of the formation of this terminal bud could explain the importance of average maximum air temperature in June in explaining the following year's height growth.

All four of the soil nutrients (Ca, Mg, K, N) from July samples of the previous year were significantly correlated with average plot height growth ($p=.05$). The potassium level in July was the most strongly correlated with average plot height growth. The second most strongly correlated was total Kjeldahl nitrogen and it was this variable which accounted for more variation among the sites and between the study years in the analysis of covariance. When the current year's shoot growth ends (middle to end of July), the terminal bud's growth increases; this increase in growth may account for the high correlations of all soil nutrients during this month.

For a few months during the growing season, significant correlations existed between seedling height growth and soil moisture and total precipitation. However, they added little in explaining either site or yearly differences. This could be a result of the fact that little moisture stress existed on the study sites during the 1985 or 1986 growing seasons. Moisture was considered limiting if soil water tension levels were above .101 -MPa (1 atm), and based on monthly pressure bomb samples, little or no moisture stress existed during

Table 2.23. Significance levels from the split plot analysis of covariance for height growth (cm) with and without the use of covariates.

Factor	No Covariates	Covariates
Site	0.0000	0.1180
Year	0.0000	0.1090
Site x Year	0.0881	0.5811

[A/] A significance level smaller than 0.05 would indicate significance (p=0.05).

these two study years. Water holding capacity at 10 to 30 cm was more successful in explaining site differences. Water holding capacity as mentioned earlier is a function of a combination of several physical soil properties which do not vary over time and it is these physical properties which are probably more important in explaining height growth differences.

Annual Diameter Growth

In diameter growth analyses, the current season's site physical and chemical and climatic data explained more site and yearly variation than that of the previous season. Thus, in diameter growth analyses, average annual growth from 1985, 1986, and 1987 were incorporated. Initial analysis of variance (without the use of covariates) found strong significant differences among sites and among study years ($p<.0001$). There also was a significant interaction between study sites and years ($p<.0001$) indicating that the trends in growth on the sites were not constant from year to year. Multiple range tests found that no significant differences ($p=.05$) existed between the average diameter growth at the ground and the control sites in 1985 or in 1986, but they were both significantly different ($p=.05$) from the average growth at the antenna site during these two study years. In 1987 there was no significant difference ($p=.05$) between the average diameter growth at the antenna and the control sites, but at the ground site significant differences ($p=.05$) existed. No covariates were identified which could satisfactorly account for these site and year differences in diameter growth.

Results from the initial analysis found nonsignificant differences ($p=.05$) with average diameter growth at the control site and one of the other test sites each year. These results seem to indicate at this time that there is no clear evidence of ELF electromagnetic field effects, but this is by no means conclusive. Results from this analysis also indicate that there seems to be a time dependent trend in the diameter growth of the seedlings and some form of a time factor needs to be introduced as a covariate. This may explain the significant site-time interaction. Future work will take this into consideration.

Seasonal Pattern of Height Growth

Height growth models based on incremental seasonal growth of the leading shoot were developed to evaluate changes that might occur in the pattern or timing of seedling height growth among the three study sites or from year to year. The amount of shoot growth expected in a given week is estimated using a difference form of a modified Chapman-Richards growth function and the cumulative air temperature degrees days at the

beginning and the end of the week. Previous work done in this field by Perala (1985) found that climatic conditions were more useful predictors and could explain much of the variation in the timing and the amount of shoot elongation among sites. Soil temperature degree days at depths of both 5 cm and 10 cm were considered, but results indicated that air temperature degree days (on a 4.4° C basis) performed best.

To further explain the variation in the system a second component was added to the model. A negative exponential component modifies the expected growth based on soil water tension (Zahner 1963). Soil water tension was calculated to estimate moisture stress because, although soil moisture content gives a measurement of the amount of water contained in the soil, it does not reflect the degree to which plants can utilize this water. The tension at which the soil holds the water determines to a large extent the degree to which a plant can absorb water. Moisture was considered restrictive if tension levels were above .101 -MPa (1 atm); when this occurred, expected growth was reduced. Soil water tension was estimated at depths of 5 and 10 cm based on soil moisture content measurements at these depths. The model performed best when incorporating soil water tension at 10 cm. Soil water tension was only available for the 1986 and 1987 growing seasons, thus only these two years are considered in this analysis.

Therefore, the model form is based on the two components, air temperature degree days and soil water tension, and is written as follows:

$$g_t = [(1 - e^{-b_1 * ATDD_2})^{b_2} - (1 - e^{-b_1 * ATDD_1})^{b_2}] * (TGRO) * (e^{b_3 * (MT - .101)})$$

where

- g_t = amount of shoot growth (0.1 cm) occurring in week t
- TGRO = expected total shoot growth (0.1 cm) in the growing season
- $ATDD_1$ = air temperature degree days (4.4° C) to the beginning of week t
- $ATDD_2$ = air temperature degree days (4.4° C) to the end of week t
- MT = average soil water tension for week t (if actual soil water tension is less that .101 -MPa, mt was set to .101 -MPa for model development)
- b_1, b_2 = estimated coefficients for air temperature degree days component
- b_3 = estimated coefficient for moisture stress component

Data were fit by nonlinear regression to a full model containing the moisture stress component as well as a reduced model composed only of accumulated air temperature degree days. This procedure was carried out for each growing season on each study site.

When the reduced growth model containing only the air temperature degree days component was fit to each site during each study year, only differences (p=.05) between study years were found for estimates of b_2 for each of the three study sites. There were no differences (p=.05) in the estimates of b_1 among the study sites or between the study years. The percent of variation explained in these particular models ranged from 87% to 90%.

To explain the yearly variation existing in the estimated coefficients b_2, the full growth model containing the soil water tension component was fit to the height growth data. In 1987 at the ground and antenna site however, average soil water tension never exceeded .101 -MPa; consequently the model was not fit to data from these two sites during that year. Results from these analyses indicate differences (p=.05) among sites and years for both coefficients b_2 and b_3. There were no differences (p=.05) in the estimates of the coefficient b_1. Regardless of the significant differences in the estimates of b_3, the coefficient of the soil water tension component, all were different from zero (p=.05) indicating the need for the soil water tension component in the overall growth model. The percent of variation explained by these models ranged from 88% to 90%.

A concept from Perala (1985) incorporating the knowledge that red pine has deterministic growth may account for the site and yearly differences in the estimates of the coefficient b_2. He contends that the duration of shoot growth varies with the total seasonal growth (i.e. as total shoot growth increases, the duration of growth also increases). Based on this concept, the coefficients b_1 and b_2 in the height growth model may be redefined in the following manner:

$$b_i = b_{i1} * TGRO^{b_{i2}}$$

where b_i are either b_1 or b_2, b_{i1} and b_{i2} are the respective coefficients now estimating b_1 or b_2, and TGRO is expected total annual shoot growth. Fitting this form of the model to the data found the effect of seasonal shoot growth to be highly significant on the coefficient b_2, but not significant on the coefficient b_1. Based on these results, the model can

now be written as follows:

$$g_t = [(1-e^{-b_1*atdd_2\ b_{21}*tgro^{b_{22}}}) - (1-e^{-b_1*atdd_1\ b_{21}*tgro^{b_{22}}})] * (tgro) * (e^{b_3*(mt-.101)})$$

where b_2 now is defined as $b_{21}*TGRO^{b_{22}}$ and all other variables are as previously defined.

When this model form was fit to data for each site and each study year (with the exception of the ground and antenna sites in 1987), yearly differences were found to be nonsignificant (p=.05) for all estimated coefficients. There were also no differences (p=.05) between any estimated coefficients at the ground and the antenna sites. However, except for estimates of b_1, these respective estimated coefficients were different (p=.05) from those at the control site. With yearly differences accounted for at each site, data from the two study years 1986 and 1987 were combined for each of the sites. The sites were then compared for differences to determine if there was any effect on shoot growth due to ELF fields. Only one significant difference (p=.05) was found in any of the coefficients estimates (Table 2.24). The estimate of b22 on the control site was slightly different from the respective estimate at the ground and the antenna sites. The 95% asymptotic confidence intervals for the estimates of the coefficients do not overlap; the 99% asymptotic confidence intervals do. These results indicate no site differences (p=.01) and therefore, no apparent effect of ELF fields on the timing of shoot elongation on red pine seedlings in this past year of low level antenna testing.

Red Pine Foliage

The objective of this work is to determine 1) whether ELF fields have any effect on the nutrition of red pine seedlings and 2) whether red pine foliar nutrient concentrations can be useful in explaining site differences in red pine growth rates.

Red pine foliage was collected from 50 seedlings per site at the time of planting, from 45 seedlings per site in October of 1984 and from 15 seedlings per site in October of the 1985 through 1988 field seasons. These sample sizes correspond to the number of seedlings used in plant moisture stress (PMS) and mycorrhizae studies with multiple measurements made on each seedling. At each collection period, current year

Table 2.24. Summary statistics for the final model with the three sites and two study years combined.

	Coefficient Estimate	Asymptotic 95% Confidence Interval
b_1	0.0069	(0.0068, 0.0070)
b_{21}	1.7601	(-2.1119, -1.4083)
b_{22}	0.4024	(0.3633, 0.4413)
b_3	-1.7601	(-2.1119, -1.4083)

Percent Variation Explained: 0.8861

needles were taken from seedlings, dried at 60^0 C and analyzed for total concentrations of N, P, K, Ca and Mg.

Progress

At this time, foliage nutrient analysis has been completed for samples taken at planting through 1987 (Table 2.25). In general, all nutrient concentrations are above or near levels reported for adequate growth of red pine. Critical foliar concentration levels have been reported for K (0.35%), Mg (0.05%), and Ca (0.12%), while concentrations of N above 1.0% and P above 0.16% have been found to be adequate for growth in plantations (Stone and Leaf, 1967; Hoyle and Mader, 1964; Alban, 1974). Nutrient concentrations are ranked in the order: N > K > Ca > P > Mg for all years sampled.

No attempts have been made to include foliage analyses in red pine growth analyses at this time. Analyses to examine site and year differences with and without covariates show no site differences for any foliar nutrient concentration (Table 2.26). There were however, significant differences for all nutrients by date as well as significant date by site interactions. While there have been similar differences in past years for all nutrients, there were sharp decreases in N and K levels from the 1986 to 1987 season. At this time it is too early to judge the significance of this, especially when concentrations are still above published values for adequate growth.

The use of various covariates, notably mycorrhizae per gram of root weight and various soil nutrients, helped to explain most of the date and date by site interactions. Since it is uncertain that mycorrhizae will be independent of ELF field effects, the use of this covariate is in question. The effective performance of soil nutrients indicates an opportunity to examine other site ambient factors and their relation to foliar concentration. Such an approach has been successfully used by Bicklehaupt *et al.* (1979). They found degree days and precipitation in the current year and in the period after cessation of height growth in the previous year (due to determinant growth of red pine) to explain yearly fluctuations in foliar nutrient levels. In addition, nutrient loadings in precipitation will also be examined as covariates in site and year comparisons. Detection limits will be calculated following the examination of these additional covariates.

Table 2.25. Foliage nutrient conentrations for red pine seedlings at ELF study sites at the time of planting and four years afterwards.

Site	N	P	K	Ca	Mg
			%		
AT PLANTING					
Ground	1.12	0.14	0.40	0.22	0.12
Antenna	1.16	0.14	0.39	0.20	0.12
Control	1.15	0.14	0.39	0.22	0.12
1984					
Ground	1.42	0.15	0.49	0.30	0.13
Antenna	1.50	0.16	0.50	0.31	0.14
Control	1.33	0.15	0.46	0.30	0.13
1985					
Ground	1.43	0.16	0.51	0.20	0.09
Antenna	1.09	0.13	0.55	0.18	0.08
Control	1.61	0.18	0.55	0.23	0.10
1986					
Ground	1.42	0.13	0.47	0.19	0.08
Antenna	1.59	0.14	0.51	0.18	0.08
Control	1.34	0.13	0.49	0.23	0.09
1987					
Ground	1.06	0.11	0.34	0.21	0.09
Antenna	1.10	0.12	0.33	0.24	0.09
Control	1.04	0.12	0.36	0.23	0.09

Table 2.26. Results of red pine foliage nutrient covariate analyses.

	P Value				
	CA	MG	K	N	P
Without Covariates					
Site	.300	.400	.227	.312	.288
Date	.000	.000	.000	.000	.000
Date x Site	.026	.134	.021	.002	.014
With Shoot Root Ratio					
Site	.294	.350	.123	.277	.336
Date	.000	.000	.000	.000	.003
Date x Site	.003	.163	.010	.002	.016
With Mycorrhizal Per Gram of Root Weight					
Site	.116	.232	.077	.393	.434
Date	.000	.000	.000	.000	.000
Date x Site	.044	.135	.363	.002	.030
With Soil Phosphorous ($Kg \cdot ha^{-1}$)					
Site	.507	.207			
Date	.198	.453			
Date x Site	.292	.069			
With Soil Nitrogen and Phosphorous ($Kg \cdot ha^{-1}$					
Site			.950		
Date			.001		
Date x Site			.050		
With Soil Magnesium and Phosphorous					
Site				.316	
Date				.008	
Date x Site				.231	
With Soil Calcium and Nitrogen					
Site					.122
Date					.967
Date x Site					.541

Red Pine Moisture Stress

Plant moisture stress (PMS) as determined by internal plant water tension is a measure of the moisture status of plants and can be a useful measure of overall physiological condition. The overall objective of the red pine moisture stress study is to quantify the PMS/growth relationship prior to and after activation of the ELF antenna and evaluate the usefulness of PMS as a covariate in the growth analysis of red pine.

Optimum tree growth is dependant on many factors such as healthy root systems which allow adequate uptake of water and nutrients. Similarly, the aboveground biomass must function properly to translocate water and nutrients from the roots to provide photosynthate for growth. A physiological change that would affect the function of the root system and aboveground biomass may also affect the growth of the plant. Such changes, may affect the internal moisture status. Thus changes in PMS may indicate changes in physiolcgical processes that affect plant growth.

Plant moisture stress can also be used to help explain growth differences between sites. Site characteristics such as soil physical and chemical properties, microsite, water holding capacity, and climate have an effect on the growth of red pine. Because red pine exhibits relatively little genetic diversity, seedling growth expresses the potential of a site to provide optimal conditions for growth. The quality of the site is thus reflected in the growth of the seedling. If site quality is not optimum, physiological growth is also not at an optimum level and this may be reflected in internal moisture status.

Finally, PMS values can be used to indicate moisture stress during periods of drought. Extended drought can reduce water uptake and reduce growth and survival of red pine seedlings. The PMS values may help explain differences in year to year growth that are due to drought conditions.

Therefore, PMS reflects the integrated effects of physiological processes and environmental conditions on seedling growth and will be evaluated as a potential covariate in the red pine growth studies.

Sampling and Data Collection

PMS sampling was conducted in years 1984 - 1988. The red pine seedlings were planted in June 1984 and became established during that growing season. PMS values were much higher in 1984 than for 1985 - 1988 due to planting shock and do not accurately reflect PMS of established seedlings. Furthermore, ambient monitoring data are not available for 1984 for use in covariate analysis. Therefore, 1984 PMS data is not included in this analysis.

Sampling in 1988 was conducted bi-weekly beginning on May 29 and continuing until August 29 at the ground, antenna, and control sites. Sampling was not conducted after this time due to cold temperatures at the scheduled time of sampling and subsequent frozen xylem water; this results in high moisture stress values that are not an accurate reflection of seedling moisture status. On each sampling date, fifteen actively growing red pines were randomly selected from each site. A one year old needle was cut from each red pine in the pre-dawn hours and immediately placed in a pressure bomb to determine internal moisture tension (PMS). During the daylight hours prior to PMS determination, basal diameter, shoot elongation, total height, and current year needle elongation were measured. The aboveground portion of each sample tree and a portion of the root system were removed from the site the afternoon following PMS determination to obtain aboveground biomass and mycorrhizae.

Progress

Plant moisture stress values varied between -.23 and -.69 MPa in 1988 (Table 2.27 and Figure 2.3).Becker *et al.*

Table 2.27. Average plant moisture stress values, 1988 (-MPa). N=15.

Date	Ground		Antenna		Control		Overall
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std Dev.	
5/26	.59	.25	.52	.19	.45	.06	$.52^{ab}$
6/6	.28	.26	.21	.10	.32	.12	$.27^{c}$
6/20	.53	.23	.38	.19	.40	.27	$.44^{a}$
7/5	.57	.26	.41	.20	.52	.26	$.50^{ab}$
7/18	.67	.59	.47	.25	.69	.30	$.61^{b}$
8/1	.27	.13	.23	.11	.39	.20	$.30^{c}$
8/15	.24	.17	.35	.22	.28	.16	$.29^{c}$
8/29	.35	.12	.45	.18	.66	.29	$.49^{ab}$
Overall	$.44^{x}$		$.38^{x}$		$.47^{x}$		

Values followed by the same letter are not significantly different (p=0.05).

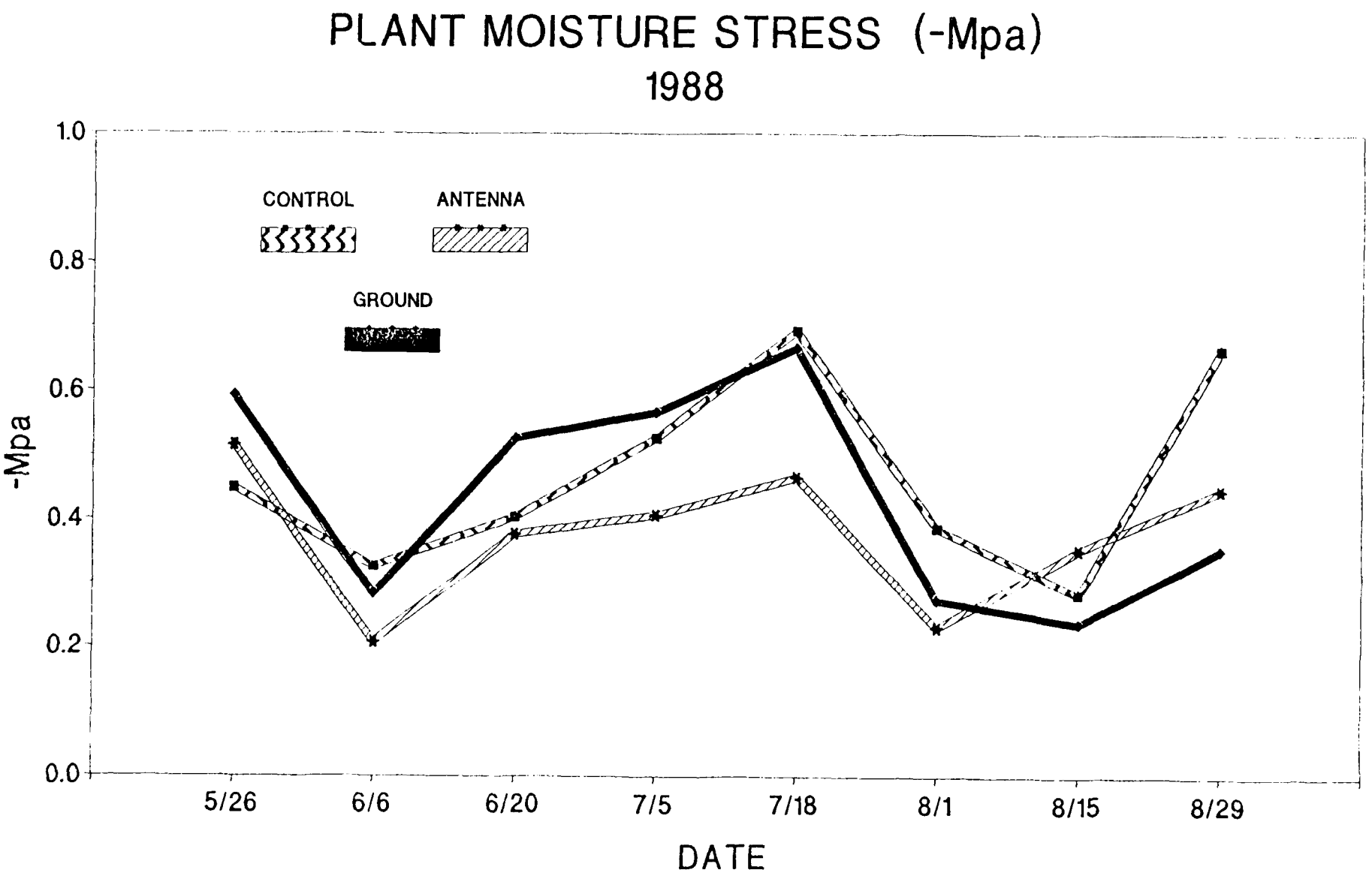
(1987) reported that PMS values ranging from -.80 to -1.1 MPa did not produce measurable reductions in red pine seedling growth. The 1988 field PMS means are well with this range as were the 1985 - 1987 values (Appendix C). The greatest stress occurs on the ground and control sites during the July 18 measurement date which follows a period of relatively high air temperatures and high soil water tension (Table 2.28). In

Table 2.28. Ambient Conditions for 1988 PMS measurements dates.
(All sites combined)

Date	Air*[a] Temp.	Air Temp. Minimum	Air Temp. Maximum	Relative* Humidity %	Relative Humidity % Minimum	Soil* Temp. 10 cm	Soil* Moisture 10 cm	Soil Water*[b] Tension 10 cm
5/26	17.1	8.2	27.9	55.7	28.3	13.7	14.4	.01
6/6	24.9	16.4	32.9	65.7	37.0	19.6	11.5	.38
6/20	25.3	18.6	30.5	55.0	26.1	20.9	6.5	.29
7/5	24.4	14.3	33.8	60.9	37.8	20.2	5.0	.96
7/18	21.1	14.8	27.3	75.7	53.7	20.3	12.8	.01
8/1	22.1	16.1	30.3	62.4	41.0	19.7	8.4	.30
8/15	20.8	13.0	30.0	59.0	28.0	20.4	15.5	.01
8/29	10.6	5.3	16.6	81.7	56.0	14.5	14.7	.01

* Daily Average
a Temperature ^{o}C
b -MP

Figure 2.3.


PLANT MOISTURE STRESS (-Mpa)
1988
CONTROL
ANTENNA
GROUND
1.0
0.8
0.6
0.4
0.2
0.0
-Mpa
5/26
6/6
6/20
7/5
7/18
8/1
8/15
8/29
DATE

addition, precipitation in July was lower in 1988 than in previous years (Fig. 1.21). It appears, however, that the effect of these conditions on PMS continued during the week of July 18 after soil water tension had decreased and soil moisture had increased. Abundant rainfall at the end of July and during August (Fig. 1.21) resulted in decreased PMS values on August 1 and 15. PMS values were also relatively high on the May 26 and August 29 measurement dates. At these times, soil moisture is relatively high but minimum daily air temperatures were the lowest for any measurement date (Table 2.26). Because PMS is measured in the pre-dawn hours, daily minimum temperature best represents the climatic conditions existing at the time of measurement.

It appears that PMS may be related to air temperature in two ways. First, during warm dry periods with increased soil water tension, transpirational forces increase the demand for water within the tree which then leads to increased moisture stress (Kramer, 1983). Second, cool temperatures effect the viscosity of the internal water which in turn increases the tension with which the water is held (Grossnickle, 1988). Grossnickle (1988) further reported that the greatest resistance to internal water flow occurs when temperatures fall below 7 ^{o}C; a condition which existed on August 29 and on several dates in 1985 (Appendix C). The importance of the relationship between temperature and soil moisture status and PMS on evaluating the effects of ELF fields on red pine will be further explored in the coming year.

Differences between PMS and measurement dates and sites in 1988 were examined through analysis of variance. Significant differences ($p=0.05$) were found in 1988 between measurement dates and in the date by site interaction, but differences between sites were not significant. Differences between measurement dates are expected due to variation in climatic conditions found throughout the growing season.

Analysis of variance of the 1985-1988 data was used to test differences in PMS between sites and years. Examination of these data indicated that the variation in PMS among plots was similar while major differences in variation were found among measurement dates. In the analysis of variance for PMS reported last year for years 1985-1987, plot within site was used as an error term in testing site and year differences. However, due to the differences in variation among measurement dates, plot within site was removed as an error term in the analysis and measurement date within year was added.

Table 2.28 Anova table for the analysis of 1985 - 1988 plant moisture stress data.

Source of Variation	df	SS	MS	F-Ratio
Year	2	SS(Y)	MS(Y)	MS(Y)/MS(E1)
Date w Year (E1)	26	SS(E1)	MS(E1)	MS(E1)/MS(WR)
Site	2	SS(S)	MS(S)	MS(S)/MS(E2)
Site by Year	6	SS(SY)	MS(SY)	MS(SY)/MS(E2)
Date w Year by Site (E2)	52	SS(E2)	MS(E2)	MS(E2)/MS(WR)
Within + Residual (WR)	1256	SS(WR)	MS(WR)	

w = within

Significant differences ($p = 0.05$) were found between years and the date interactions with year and site, but site, and the year by site interaction were not significant. Because PMS is being considered as a possible covariate in the red pine growth analysis we must determine whether PMS is independent of ELF fields. This can be accomplished by analysis of covariance. If covariates can explain these differences then we can conclude that PMS is independent of ELF fields.

Prior to covariate analysis, correlations were calculated between tree factors, ambient variables and PMS. In the PMS covariate analysis conducted in 1985 - 1987, weekly averages of the ambient variables were used to calculate correlations and in the analysis of covariance. For the 1985 - 1988 analysis, daily ambient data for each measurement date were used. These variables include those that were directly measured such as air and soil temperature, relative humidity, and precipitation. In addition, soil water tension (see Element 1: Ambient Monitoring), vapor pressure gradient (Cleary *et al.* 1978), and precipitation-effectiveness (PE) index (Barbour, 1980) were calculated from the direct ambient measurements. Vapor pressure gradient (KPa) is a measure of the moisture gradient between the tree and the surrounding air assuming that the tree is saturated at any given temperature. The rate of water loss from a tree is a function of the vapor pressure gradient with a larger gradient resulting in more rapid water loss. The PE index incorporates both precipitation and temperature into a single value and has been shown to be related to vegetative growth (Barbour *et al.*, 1980). Calculations used to estimate vapor pressure gradient

and PE index are shown below:

Vapor pressure gradient = $E_s - E_a$

Where:
E_s = Saturation vapor pressure at a given temperature
E_a = Actual vapor pressure at that same temperature

Precipitation-effectiveness index = $[(P/T-10)]^{10/9}$

Where: P = Daily precipitation
T = Average daily air temperature ^{o}C

Tree measurement variables were not considered as possible covariates because it is uncertain whether these variables are independent of ELF fields. Variables with the highest significant (p=0.05) correlations were selected for inclusion in the analysis of covariance (Table 2.30).

Table 2.30. Correlations between PMS and selected variables considered for inclusion in the analysis of covariance.

Variable	Correlation
Average daily air temperature (^{o}C)	.51*
Daily minimum air temperature (^{o}C)	.48*
Daily maximum air temperature (^{o}C)	.46*
Average daily soil temperature - 5 cm (^{o}C)	.47*
Daily minimum soil temperature - 5 cm (^{o}C)	.50*
Daily maximum soil temperature - 5 cm (^{o}C)	.33*
Average daily soil temperature - 10 cm (^{o}C)	.45*
Daily minimum soil temperature - 10 cm (^{o}C)	.36*
Daily minimum soil temperature - 10 cm (^{o}C)	.48*
Average daily soil moisture % - 5 cm	.14*
Average daily soil moisture % - 10 cm	.19*
Precipitation received on date of measurement (in.)	.05*
Average daily relative humidity %	.10*
Average daily soil water tension - 5 cm (-MPa)	-.01
Average daily soil water tension - 10 cm (-MPa)	.04
Tree age	.44*
Vapor pressure gradient (KPa)	.15*
Precipitation-effectiveness index	-.33*

* Significant at p=0.05

Temperature variables had the highest correlations while soil moisture, vapor pressure gradient, and soil water tension were not as well correlated with PMS.

The variables listed in Table 2.30 were used singly or in combination as covariates to explain existing differences in PMS. Average daily air temperature and tree age did the best in terms of reducing significance levels (Table 2.31).

Table 2.31. Significance levels from analysis of covariance for PMS with average daily temperature and tree age as covariates.

Factor	P-value
Year	.147
Date within Year	.000
Site	.455
Site by Year	.578
Date within Year by Site	.000

These covariates reduced variability in PMS among years to non significant levels but did not explain the differences for the date within year and date within year by site interactions. Additional work with ambient covariates is required to help in explaining these differences. As discussed earlier, 1988 PMS values increased following a period or warm temperatures and soil water tension and remained high after these conditions improved suggesting that a lag period may be appropriate in analyzing differences in measurement dates. Thus, further analysis will be conducted to evaluate whether these differences can be attributed to the ELF system. However, the lack of significant differences between sites, among years, and in the year by site interaction indicate that use of the ELF system had no detectable effects on PMS for these factors.

Future efforts will focus on examining the relationship between temperature, soil water tension, and PMS. Although soil moisture was significantly correlated with PMS, soil water tension was not. However, soil moisture was not as useful as temperature in explaining existing differences in PMS when used by itself or in combination with temperature. In addition, it has been reported that soil moisture deficits are the primary cause of internal moisture deficits (Kramer and Koslowski, 1979) but this relationship has not been shown to be an important factor in the covariate analysis. It has also been reported that soil water tensions less than -.20 Mpa can inhibit tree growth (Glerum and Pierpoint, 1968). In light of our finding and of those reported in the literature, further examination of the relationship between PMS and soil moisture, soil water tension, temperature, and transpiration

will be important in terms of evaluating effects of ELF fields on PMS.

Armillaria

Progress

Since there were significant differences in *Armillaria* caused mortality of red pine among sites in past years, a primary effort in this study has been to identify possible causal agents for these differences that could be used in covariate analyses. Red pine mortality was monitored on each plot with fungal isolates taken from each dying or dead seedling to confirm the presence of *Armillaria*. Cultures are being maintained in the laboratory for a permanent record. Particular attention has focused on identifying *Armillaria* clones on each plot to determine spatial distribution. This information will also be compared over years to determine whether the occurance of a particular clone is increasing or decreasing.

Height of dead and dying seedlings was also measured this past year to evaluate infection interactions with seedling size. Since mortality is currently greatest at the control site where seedlings are larger, some of the site differences may be due to seedlings being larger targets for invasion by *Armillaria*. Thus mortality may be lower at antenna and ground sites only until the seedlings attain the size of those at the control site.

To investigate host-pathogen relationships, a survey was conducted to identify stump species and evaluate stump vigor based on height of the tallest and total number of sprouts. This was done in response to observations of greater red pine mortality in areas with paper birch stumps which show limited sprouting ability in open areas. On each stump, isolates were collected to determine infection relationships to stump vigor and whether there is a clone-host specialization. Since both seedlings and stumps have been mapped on the plots, this information will also be used to evaluate the spatial distribution of clones and mortality of red pine.

Several isolates from each clone at the control site are being sent to the University of Toronto for mitochondrial DNA studies. These are used to positively characterize and identify *Armillaria* to the species level, further evaluating the host-parasite relations at the ELF sites.

The hardwood stands were also examined for *Armillaria* fruiting bodies this past year with isolates collected for clonal identification and characterization. This was an expanded effort of the yearly disease survey which is done to

evaluate possible changes in forest stand health. Since the current hardwood stand is very similar in structure and composition to the stand formerly occupying the present plantation plots, this information can also be used to evaluate changes in the occurence of various *Armillaria* clones which have taken place since plantation establishment.

ELEMENT 3: PHENOPHASE DESCRIPTION AND DOCUMENTATION

The herbaceous layer of a northern hardwood ecosystem is one of the most ecologically important components of these forests. Characteristics of these plants provide information on this ecosystem's response to many factors. Phenological events, such as timing of stem elongation, bud break, leaf expansion, flowering, fruiting and leaf senescense have been used to monitor and assess a plant's response to climatic and edaphic factors. Morphological characteristics, such as leaf area, stem length, number of buds, number of leaves, number of flowers, and number of fruit also provide necessary information on a plant's response to climatic and edaphic factors. This information can then be used to assess the overall vigor of that plant to withstand major perturbations. It is important, therefore, to monitor the phenological events and morphological characteristics of herbaceous species when evaluating the response of an ecosystem to ELF fields.

Starflower, *Trientalis borealis* Raf., is an important herbaceous species on the control and ELF antenna sites. Because phenophases of starflower have been well documented in northern Wisconsin (Anderson and Loucks, 1973) and in Canada (Helenurm and Barrett,1987), it's response to ELF fields can be documented and evaluated with some reliability and comparability.

The objectives of this element are to: 1) describe and document specific phenological events and morphological characteristics of *Trientalis borealis* prior to and during operational use of the ELF antenna and 2) use these data to test hypotheses of possible changes in physiological and phenological processes due to ELF fields.

The main null hypothesis to be tested each year is:

> H_0: There is no difference in the onset of flowering and the timing of leaf expansion of *Trientalis borealis* between the antenna and control sites within a year.

The hypothesis to be tested over all years is:

> H_0: There is no difference in the onset of flowering and the timing of leaf expansion of *Trientalis borealis* before and after the ELF antenna becomes operational.

Morphological characteristics (number of buds, number of flowers, number of fruit, and maximum leaf area) will also be analyzed within the context of these hypotheses. Ambient characteristics within each year will be tested to determine if they explain significant differences among years and sites for the phenological and morphological characteristics.

Sampling and Data Collection

During the 1988 field season, data were collected at the antenna and control sites between May 2 and August 25. Each site was sampled twice a week from May 2 until June 16 to delineate flowering periods and leaf expansion with greater precision. Thereafter, each site was sampled once a week until August 25. Parameters measured per plant for each observation period included stem length, length and width of the largest leaf, number of leaves, number of buds, number of flowers, number of fruit, number of yellow leaves (leaves senescing), and number of brown leaves. To ensure an adequate representation of starflower phenophases, a minimum sample size of 200 individual plants per site was maintained for each observation period during leaf expansion, bud formation, and flowering. To achieve this goal, a single transect line was run and subsequently divided into permanent 1 m^2 subplots. Individual plants within each subplot were then numbered and tagged until a normal distribution of mean stem length was attained. Stem length was used as the response variable for this determination because it is a prime indicator of a herbaceous plant's potential sexual productivity. A normal distribution of stem length insures an adequate representation of the population for analysis of variance techniques. The number of meter square subplots required to obtain a minimum sample size of 200 plants varied between the antenna and control site and among weeks sampled. To reduce bias in choosing the 200th individual, all individual plants were tagged and measured in the subplot where the 200th plant occurred, hence sample size was unequal across sampling days. This sampling method was maintained for each individual plant until tagged individuals began to die or were eaten. Thereafter, observations were taken only on the remaining tagged individuals. Maximum leaf area was estimated for each plant by 1) taking the largest leaves on 15 randomly sampled plants off the herbaceous reserves at each observation period in 1986, 1987, and 1988, 2) measuring leaf length, leaf width and leaf area, and 3) developing regression equations for leaf area (dependent variable) using leaf length and width as independent variables.

This year, a separate analysis was run on the effects of handling individual plants. Sample plants outside the measured transect were randomly chosen within the herbaceous reserves on one occasion (June 16). Three morphological characteristics (stem length, leaf length, and leaf width) were used as the response variables. Results indicate that there is a significant decrease in the size of "handled" plants (Table 3.1) on both the control and he antenna site.

Table 3.1. Means, standard deviations, and significant relationships by site and location for starflower stem length, leaf length, and leaf width (Different letters indicate significant differences in the means ($p < 0.05$)).

Site and Location	STEM LENGTH Mean	Standard Deviation
Control - Unhandled	9.58[b]	2.10
Control - Handled	8.02[a]	3.31
Antenna - Unhandled	10.64[c]	2.36
Antenna - Handled	7.12[a]	2.87

Site and Location	LEAF LENGTH Mean	Standard Deviation
Control - Unhandled	5.15[b]	1.18
Control - Handled	4.17[a]	1.48
Antenna - Unhandled	6.00[b]	1.35
Antenna - Handled	4.04[a]	1.58

Site and Location	LEAF WIDTH Mean	Standard Deviation
Control - Unhandled	1.84[b]	0.43
Control - Handled	1.47[a]	0.46
Antenna - Unhandled	2.03[b]	0.44
Antenna - Handled	1.51[a]	0.47

While these differences may be attributed to handling, different sampling methods (random versus fixed plot) and the microclimate of each sampled area also could have had a pronounced effect on the size of individual plants. To provide a more accurate and consistent means from which to judge the effects of handling on starflower plant size, three $1m^2$ square plots adjacent to three randomly chosen transect plots will be established in 1989 on both the antenna and the control sites. Care will be taken to ensure the least amount of handling occurs to plants in the "unhandled" plots.

Progress

Phenological characteristics

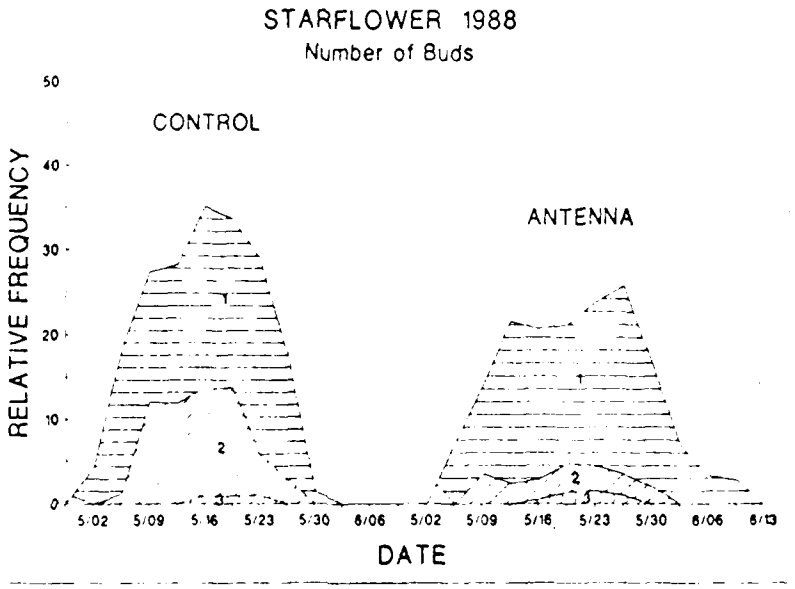
In 1988, stem expansion on the antenna site began one week earlier than stem expansion on the control site, while leaf expansion occurred at similar times on both sites. Bud formation on the control site began before bud formation on the antenna site (Figure 3.1A). Flowering on the antenna site began around the same time (May 16) as flowering on the control site (Figure 3.1B). As with bud formation, fruiting occurred one week earlier on the control site compared with the antenna site (May 23 versus May 30) (Figures 3.2A and 3.2B). Leaf senescence (yellowing leaves) began 3 days earlier on the antenna site (June 6 versus June 9) (Figures 3.3A and 3.3B) while the occurrence of dead leaves (brown leaves) began at the same time on both sites (Figures 3.4A and 3.4B). Similar relationships occurred either in the 1987, 1986, or 1985 growing seasons indicating that low level ELF system testing that were present during the 1988 growing season had no distinguishable effect on the timing of starflower's phenological events (Appendix D).

In observing the phenological events of flowering and fruiting on both sites, each event began when the previous event was at its maximum except for flowering on the antenna site (Figure 3.5A and 3.5B). The proportion of plants flowering was significantly lower (<10%) than in previous years (>20%) indicating that there is some phenological and morphological change occurring. This change may be due to climate, handling, ELF, or to interactions among these factors. At this time, differences in the relationships of phenological events between the antenna and control sites cannot be discerned except in the proportion of plants flowering.

Analysis of covariance (ANCOVA) was used to determine if climate variables could be used to explain differences in stem expansion (cm/time period), leaf expansion (cm/time period), and leaf area expansion (cm^2/time period) between sites (antenna vs control), years, and site by years (Table 3.2). The same ANCOVA was used in 1988 as in 1987. Error terms (1 and 2) for this year included sampling period (P) and not weekly averages as in 1987. In the initial analysis of variance without covariates, stem expansion, leaf expansion, and area expansion on the antenna site were significantly different from the control site (Table 3.3) Year and site/year interaction were also determined to be significantly different except for leaf length differences among years (Table 3.3A). All climate variables (Element 1, this report) were significantly correlated ($p<0.01$) to all three response variables. Scatterplots of soil temperature degree days running total indicated that the variation in the response variables increased with increasing soil temperature (e.g.

Figure 3.1. Relative frequency for number of plants with one, two, or three buds (A) and number of plants with one or more flowers (B) by sampling date on the control and the antenna sites.

A



B

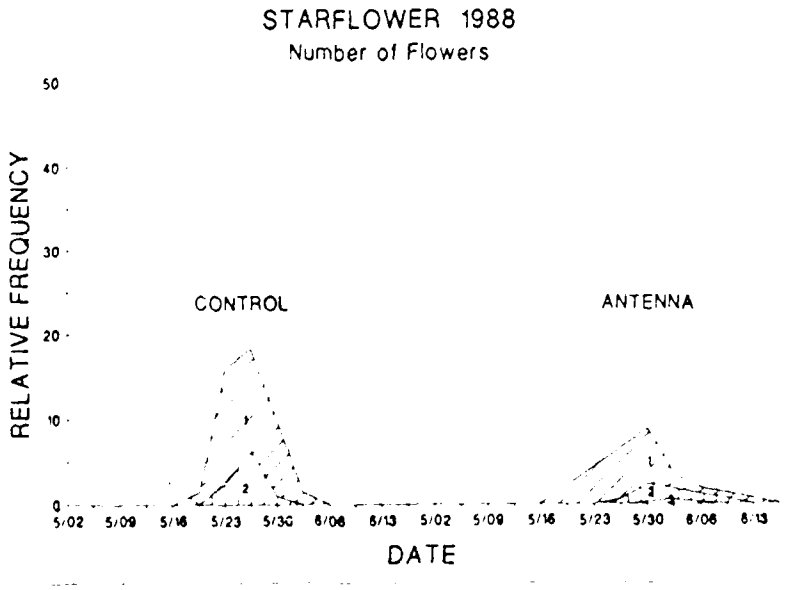
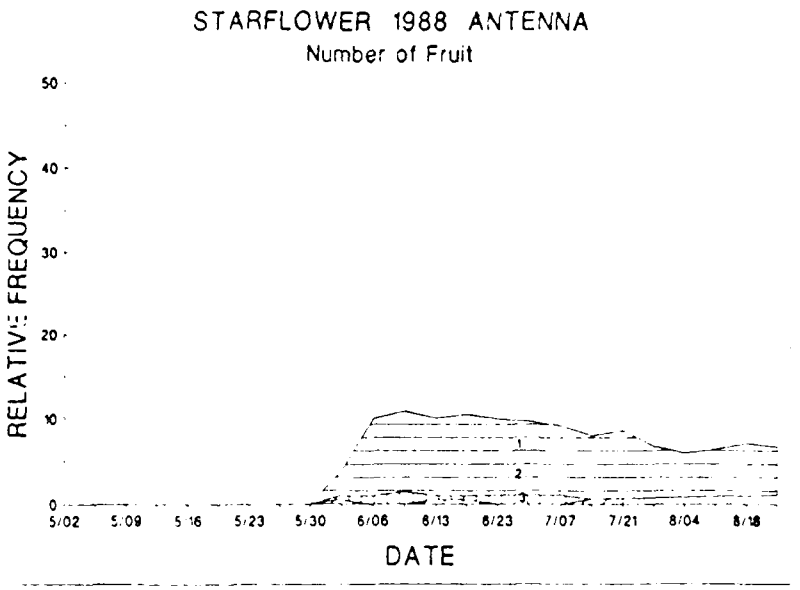


Figure 3.2. Relative frequency for number of plants with one, two, or three fruit by sampling date on the antenna site (A) and the control site (B).

A



B

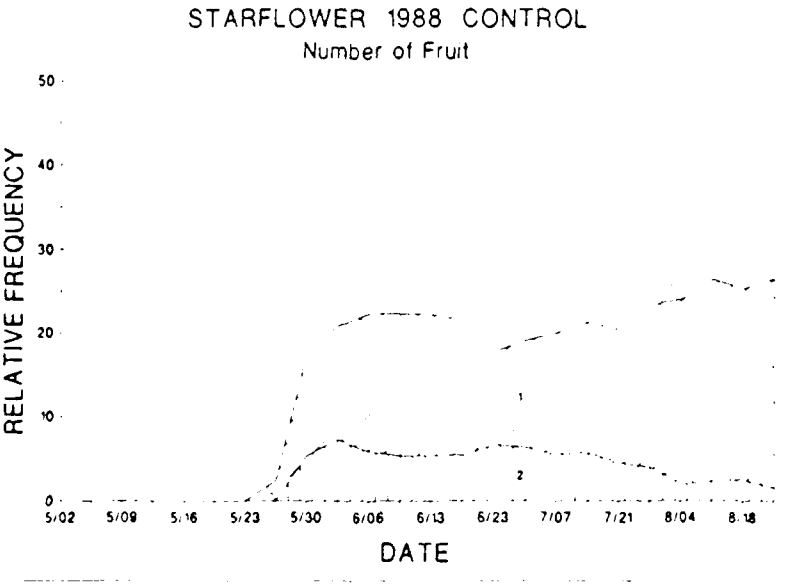


Figure 3.3. Relative frequency for number of plants with one or more leaves senescing by sampling date on the antenna site (A) and the control site (B).

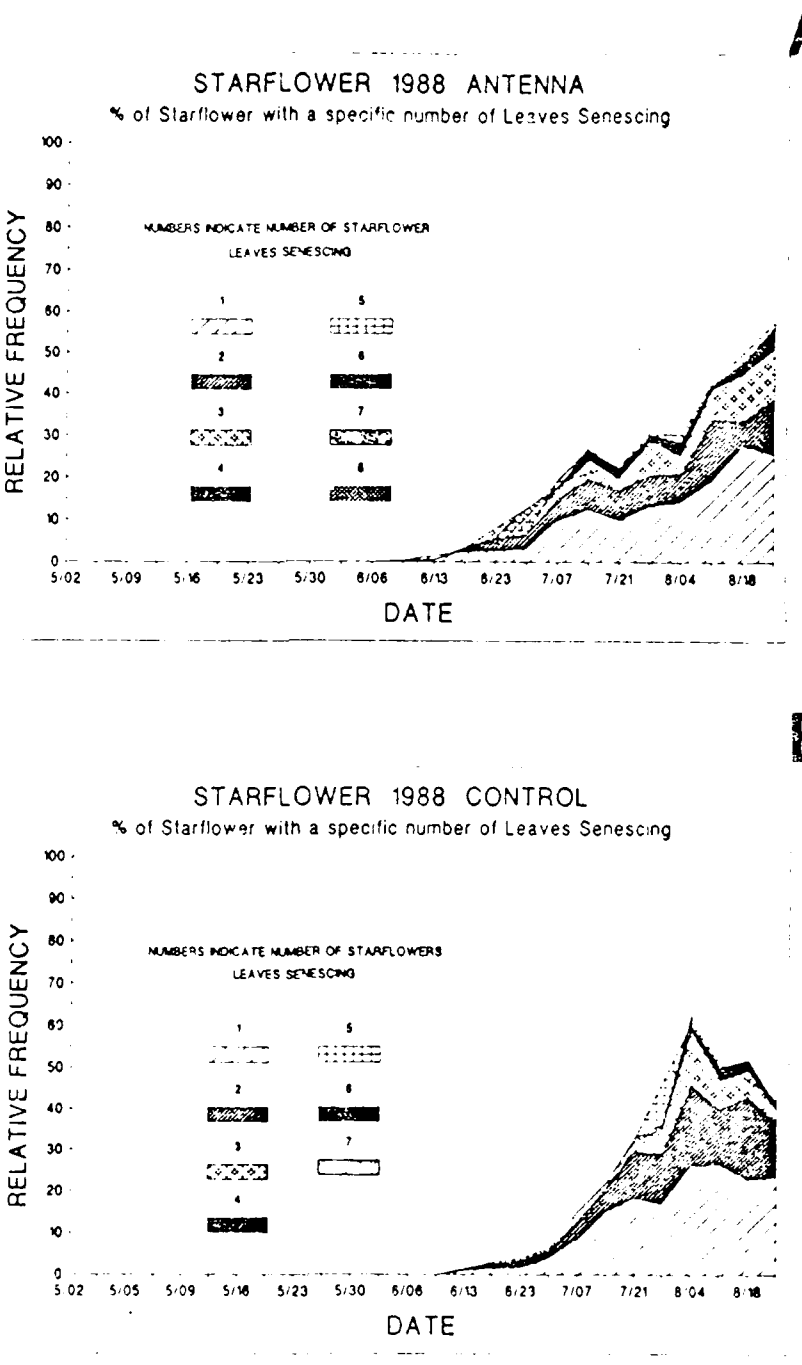
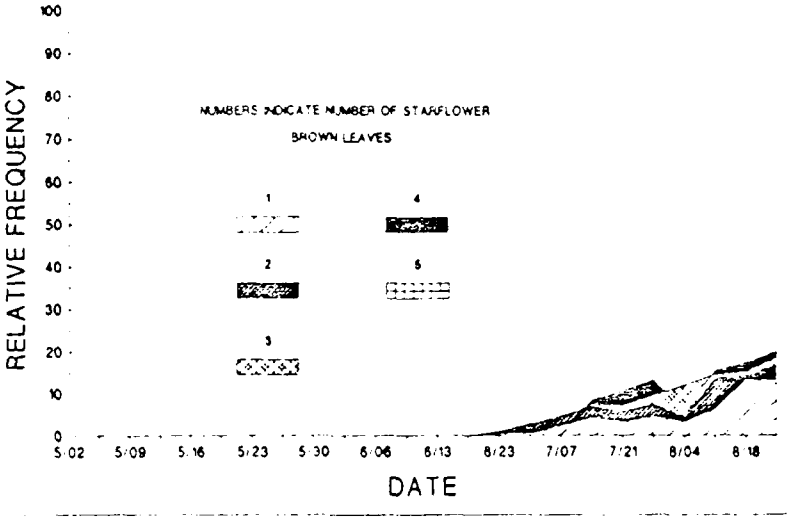


Figure 3.4. Relative frequency for number of plants with one or more brown leaves by sampling date on the antenna site (A) and the control site (B).

A



B

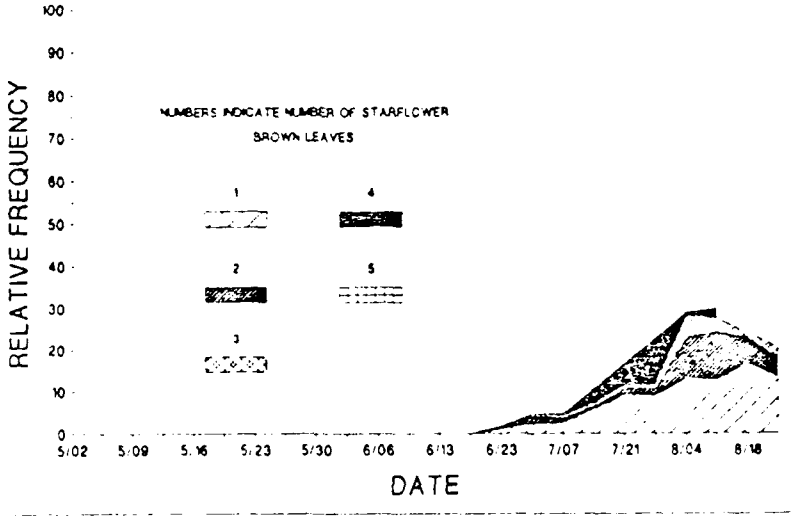


Figure 3.5. Comparison of the relative frequency and proportion of plants with one or more buds, flowers, and fruit by sampling date on the antenna site (A) and the control site (B).

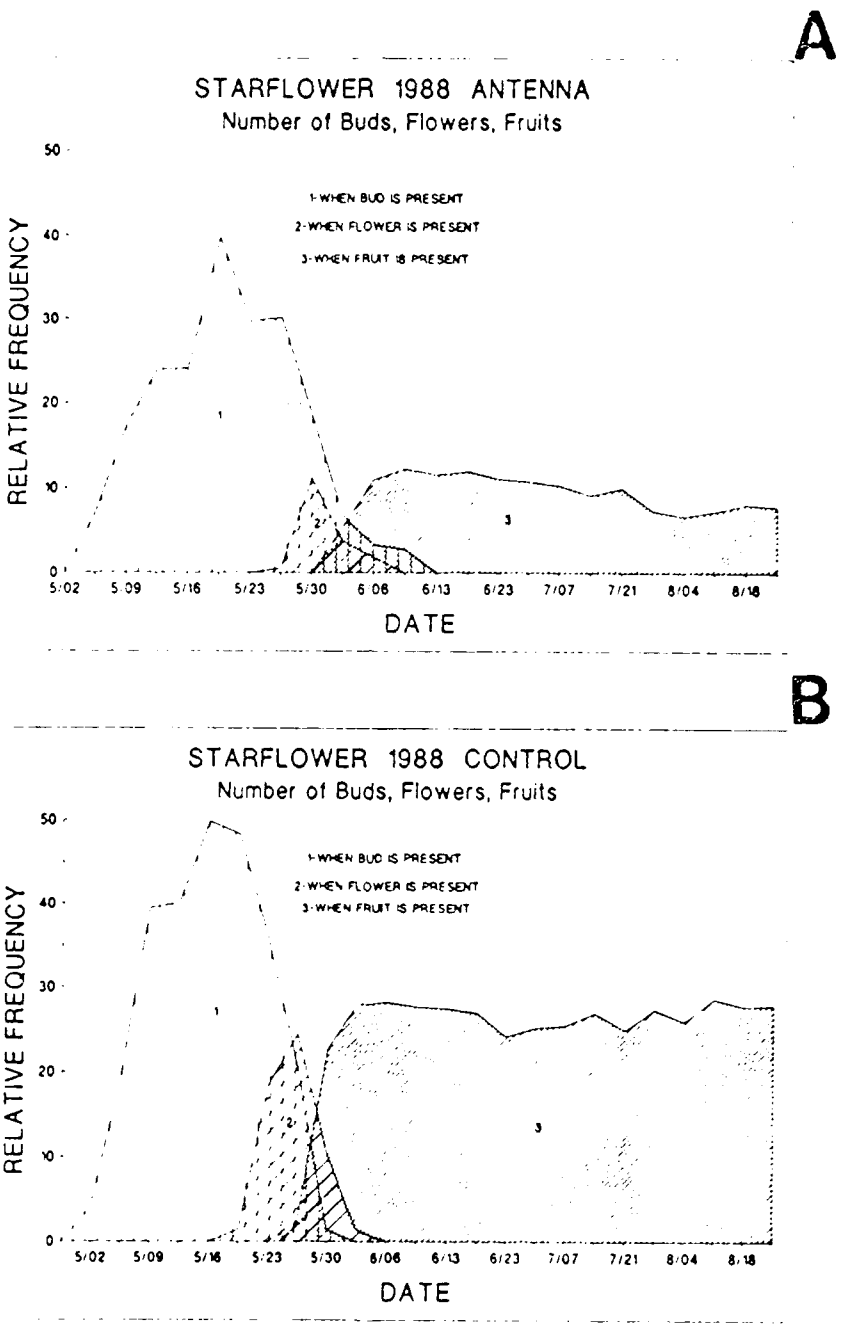


Table 3.2. Analysis of Covariance table for stem expansion, leaf expansion, and leaf area expansion.

Source of Variation	df	SS	MS	F
Year	3	SS_y	MS_y	MS_y/MS_{e1}
Covariates	#	SS_{cy}	MS_c	MS_c/MS_{e1}
Error 1 (P/Y)	44-#	SS_{e1}	MS_{e1}	
Site	1	SS_s	MS_s	MS_s/MS_{e2}
Site by Year	3	SS_{sy}	MS_{sy}	MS_{sy}/MS_{e2}
Covariates	#	SS_{cs}	MS_{cs}	MS_{cs}/Ms_{e2}
Error 3 (SxP/Y)	44-#	SS_{e2}	MS_{e2}	

Table 3.3. Results of ANCOVA (p values) to determine significant differences in stem expansion (STEM), leaf expansion (LGTH), and leaf area expansion (LAREA) between sites, years, and years by site.

A) No Covariates

Source of Variation	STEM	LGTH	LAREA
Year	0.00	0.17	0.00
Site	0.00	0.00	0.00
Site by Year	0.00	0.00	0.00

B) Covariates - Natural Log (Soil Temperature Degree Days Running Total at 10 cm) + Natural Log (Soil Temperature Degree days Running Total at 5 cm) + Air Temperature Degree DAys Running Total + Minimum Relative Humidity + Maximum Solar Radiation

Source of Variation	STEM	LGTH	LAREA
Year	0.00	NS	0.00
Site	NS	NS	NS
Site by Year	NS	NS	NS

non-constant variance). This problem was solved by taking the natural log of soil temperature degree days running total. The following variables were most highly correlated to area expansion, leaf expansion, and stem expansion: 1) maximum solar radiation (r=-0.64, -0.47, -0.23, respectively), 2) natural log of soil temperature degree days running total at 10 cm (r=0.44, 0.71, 0.32), 3) natural log of soil temperature degree day running total at 5 cm (r=0.47, 0.70, 0.31), 4) air temperature degree days running total (r=0.30, 0.53, 0.23), and 5) minimum relative humidity (r=0.21, 0.37, 0.24, respectively). These climate factors were added into the analysis of variance as covariates to explain differences in area, leaf, and stem expansion. Due to missing information for relative humidity and solar radiation, the first year, 1985, was dropped from further analysis. The use of covariates helped explain significant amounts of variation in leaf area between sites, among years and site by years (Table 3.3B). Significant differences in leaf expansion among years were also explained using covariates. Differences in stem and area expansion among years were, however, still evident. Significantly lower area expansions in 1988 versus 1987 and 1986 were attributed to the leaf area equations used in 1988 (Table 3.4). Yearly ranks of stem heights ranged from the highest in 1987 to the lowest in 1986; 1988 being in the middle. The addition of other climatic factors as covariates did not yield better results.

Table 3.4. Leaf area (LA in mm^2) equations for each site in each year and for all sites and all years using leaf width (Lw mm^2) and leaf length (Ll mm^2).

Site (Year)	Equation	$S_{y.x}$[1]
Control Site (1986)	LA = 0.09 + 0.55 (Lw x Ll)	0.20
Control Site (1987)	LA = 0.11 + 0.56 (Lw x Ll)	0.18
Control Site (1988)	LA = 0.40 + 0.52 (Lw x Ll)	0.68
Antenna Site (1986)	LA = 0.13 + 0.55 (Lw x Ll)	0.26
Antenna Site (1987)	LA = 0.13 + 0.56 (Lw x Ll)	0.34
Antenna Site (1988)	LA = 0.32 + 0.52 (Lw x Ll)	0.60

[1] Standard error of regression

Morphological Characteristics

Three buds per plant were observed on both the antenna site and the control site (Figure 3.1A). More plants produced buds on the control site than on the antenna site (Figure 3.1A). The amount of plants that produced flowers were lower on the antenna site versus the control site (Figure 3.1B). The number of flowers per plant were greater on the antenna site. More fruit (>2 fruits per plant) were observed on plants on the antenna site versus those on the control site (Figures 3.2A and 3.2B). However, as with the number of buds, and the number of flowers, more plants produced fruit on the control site than on the antenna site. The antenna and control sites exhibited the same amount of plants that produced yellow leaves (Figures 3.3A and 3.3B). The plants with brown leaves were lower in number on the antenna than on the control site. Except for the proportion of plants flowering, similar relationships were seen in the 1985, 1986, and 1987 growing seasons (Appendix D).

Using regression analysis, linear equations were fit to observations of leaf area using leaf length and leaf width measured on destructively sampled starflower plants off the herbaceous reserves for each year (1986, 1987, 1988) on each site (Table 3.4). The independent variable of leaf width x leaf length explained 99 percent of the variation in leaf area for both sites in 1986 and 1987. Ninety-two and 96 percent of the variation in leaf areas was explained using the variable leaf width x leaf length for the control and the antenna, respectively, in 1988. Higher standard errors occurred with the development of the 1988 curves (Table 3.2). Possible causes of increased error in 1988 could be due to inaccuracies in leaf length and leaf width measurements and/or leaf sampling in the field. Differences could also be due to changes in morphological characteristics. Analysis of the variation in leaf areas will continue.

Coefficients (intercepts and slopes) were tested to determine if there were significant differences ($p = 0.05$) between sites (antenna vs control) and among years (1986, 1987, and 1988). Site-year interactions were also examined. Significant yearly differences ($p < 0.001$) in both the slopes and the intercepts were determined. Intercepts for the antenna and control sites in 1988 were significantly greater than for 1986 and 1987 while slopes for the antenna and control sites were signifcantly lower in 1988 than for 1986 and 1987. These differences may be due to the increase in the amount of solar radiation in 1988 compared to other years (Element 1, this report). There were no differences in coefficients between sites or among site/year interactions.

Summary

At this time, significant variation in stem expansion, leaf expansion, and leaf area expansion between the antenna and the control site can be explained using soil temperature degree days running total at 5 cm and at 10 cm, air temperature degree days running total, minimum relative humidity, and maximum solar radiation. The ELF fields in 1988 did not seem to affect starflower's leaf and stem expansion, however, the number of plants flowering has been significantly reduced in 1988. There is some concern at this time that the handling of these plants is reducing their size. Similar reductions were found, however, on both sites. Monitoring these reductions will continue next year. Additional analyses on the relationship of each phenological event to the prior event will continue. Monitoring of starflower's morphological and phenological characteristics between sites will also continue.

Element 4: POPULATION DYNAMICS OF MYCORRHIZAL MACROFUNGI VIA SPOROCARP PRODUCTION

Mycorrhizae represent the integrating bridge between plant root systems and the surrounding soil. Because mycorrhizae represent a mutually beneficial relationship, they may be sensitive indicators of treatment effects on either the host or the parasite, or both. Thus, mycorrhizae are an obvious area of study for evaluation of potential ecosystem perturbations such as those associated with ELF fields.

Detailed study of ectomycorrhizae formation has been directed to the three red pine study plantations (Element 5), because of the base of existing knowledge on red pine growth and the relative ease of studying plantation seedling root systems compared to those of mature mixed hardwoods. Nevertheless, the mixed hardwood stands at the ANtenna and Control sites offer an excellent opportunity to describe and quantify a portion of the indigenous ectomycorrhizal fungus community via the population dynamics of sporocarp production. Sporocarp production represents a fungal investment of energy obtained from the host in the perpetuation of the fungus species. As such, the extent of sporocarp production reflects the combined vigor of the host/parasite system. Biologically significant impacts on either host or parasite should result in adjusted fruiting patterns by the mycorrhizal fungus species involved.

The objective of this study is to use sporocarp production by selected ectomycorrhizal macrofungi indigenous to the Antenna and Ground site herbaceous reserve plots as an indicator of change in hardwood stand or mycorrhizal fungus health. The overall null hypothesis proposed in this phase of the study is:

H_O There is no difference in sporocarp production to selected mycorrhizal fungi before and after the ELF antenna becomes operational.

Sampling and Data Collection

Population dynamics of selected ectomycorrhizal macrofungi indigenous to the hardwood stands at the Antenna and Control sites are being evaluated by periodic monitoring of sporocarp production on two sets of three contiguous 30m x 35m herbaceous reserve plots. Counted sporocarps were slit vertically so that they would not be accidentally retallied during subsequent visits. Counted sporocarps were not removed, in order to minimize impact on subsequent flushes (Manachere 1985).

Because sporocarp production is closely tied to host photosynthetic activity (Last *et al.* 1984) and host genotype(Last *et al.* 1984, Mason *et al.* 1984), fruiting by ectomycorrhizal macrofungi is expected to proceed as regularly

as the relatively stable study stand structure and climate will permit. The relatively large size of each study plot should reduce variability among yearly sporocarp counts by absorbing the effect among years of spatial redistribution of sporocarp production around host trees. Differences in sporocarp production among years may also be minimized by composting several years' counts for comparisons before and after the ELF antenna becomes operational.

Progress

Because of wide variability in sporocarp data, these counts may be of limited value in determining ELF field effects. This past year, no field work was performed because of this lack of sensitivity and conflicts in work schedules as the expanded Armillaria sampling season coincides with that of sporocarp counts. Efforts had been targeted to a final statistical evaluation of current data.

Element 5. MYCORRHIZAE CHARACTERIZATION AND ROOT GROWTH

Mycorrhizae of plantation red pine seedlings have been chosen as biological components of the soil ecosystem sensitive enough to reflect perturbations which might be caused by ELF fields. Mycorrhizae are symbiotic structures representing a finely balanced physiological relationship between tree roots and specialized fungi, providing mutual benefit to both partners of the symbiosis. Mycorrhizal fungi are obligately bound to their host requiring photosynthate from the tree for their energy source. In return, the matrix of mycorrhizal fungus mycelium which permeates the forest floor and mineral soil from colonized roots provides the host tree with scarce minerals and water more efficiently than possible without its fungal partner. Although many types of mycorrhizae occur, this study deals only with ectomycorrhizae formed on the root systems of pine.

Mycorrhizae, being composed of two kinds of organisms (though sometimes several fungi may be involved) that make up a major part of the forest ecosystem, are likely to be sensitive indicators of subtle environmental perturbations. Mycorrhizal fungi are obligate symbionts, directly dependent on their partner's physiology for their health. Thus mycorrhiza formation and numbers will be sensitive to factors affecting either the fungus component or the host plant component.

Mycorrhizae have been selected for evaluation in other studies which require sensitive indicators of subtle environmental changes. Recent studies designed to monitor the effects of acid rain on the forest ecosystem used mycorrhizal numbers as the parameter of assessment (Reich *et al.* 1985, Shafer *et al.* 1985, Stroo and Alexander 1985, Dighton and Skeffington 1987). Similar studies examined mycorrhizae as affected by ozone and air pollution (Kowalski 1987, Reich *et al.* 1985, Mejstrik and Cudlin 1987) and heavy metal buildup in soils (Jones and Hutchinson 1986). Data concerning mycorrhizae are especially valuable when collected along with other measures of plant response, such as growth and moisture stress, as is being done in this study. ELF effects not directly evoking a measurable tree response could detectably alter the more discriminating mycorrhizal fungus component. Data regarding mycorrhizae of a host tree can also be used to substantiate responses seen in other measures of tree productivity.

Populations of mycorrhizae developing at each red pine plantation site are being compared with each other at monthly intervals and with corresponding monthly intervals from previous years. The basic experimental units are individual red pine seedlings. Mycorrhizae are categorized into morphological types which are produced by different fungal associations with red pine. Changes in both the frequency of occurrence for different mycorrhizal types and the total numbers of mycorrhizae per seedling are quantified for

analysis both within and among years as well as among sites. Data for analysis are expressed as the number of mycorrhizae per gram of seedling root mass (oven dry weight (o.d.w.) 60°C). The working null hypothesis states that there are no differences in population densities of different types of mycorrhizal root tips on red pine seedlings at the Ground Antenna and Control sites, before or after the ELF antenna becomes operational. Changes reflected by possible alternative hypotheses include, 1) shifts in population species composition, 2) increases or decreases of total mycorrhizae density, and 3) changes in character of mycorrhizal morphology type.

Sampling and Data Collection

In conjunction with Element 2, Tree Productivity, fifteen red pine seedlings per site (five per subplot replicate) were sampled for six months during the 1988 growing season, as was done the previous three years. Seedlings for mycorrhizal analysis were simultaneously measured for aboveground growth parameters and moisture stress. To retrieve mycorrhizae-bearing lateral roots, a soil sample approximately 22 cm in diameter and 22 cm deep was excavated with a shovel adjacent to each study seedling. Red pine seedling lateral roots were extracted from this sample in the field to obtain approximately 30 to 60 cm of total root length. A single excavation usually provided the amount required, but occasionally another sample was required at an alternate location adjacent to the seedling. Lateral roots from each seedling with adherent soil were wrapped tightly in individual plastic bags, placed in a cooler and transported to the laboratory where they were refrigerated. Within two to three days the lateral roots were rinsed first in a small volume of distilled water (1:1 water to root/soil volume) for rhizosphere soil pH determination, then washed gently in tap water, placed in a fresh volume of tap water and refrigerated. Approximately 0.25 g roots (fresh weight) per sample were removed at this time for actinomycete enumeration (ELF, Litter Decomposition and Microflora Study). Counting of mycorrhizal tips began immediately and was usually completed within three weeks of the field sampling date.

A shallow white pan containing a small amount of water was used during the root sectioning and counting operation. The roots were cut to obtain as many 3 cm segments and as few segments less than 3 cm as possible. Branching portions were separated from segments if they were greater than 1 cm in length. Branching portions less than 1 cm were included as part of the root segment to which they were attached. As each 3 cm root segment was counted, its diameter and number of mycorrhizae were recorded. A mycorrhiza is defined, for counting purposes in this study, as a terminal mycorrhizal root tip at least 1.0 mm in length; hence a mature dichotomously branched mycorrhizal root tip would be tallied

as two mycorrhizae. Upon completion of counting a total of 30 3 cm root segments per seedling, counted root segments were collectively dried at 60°C to constant mass and weighed. Mycorrhiza counts for each seedling are expressed as mycorrhizae per gram (o.d.w.) of lateral root. This measure has been used in other root studies examining mycorrhizae dynamics in forest ecosystems (Harvey *et al.* 1987).

The most common mycorrhizae present continue to be represented by a fairly uniform morphology. They range in color from tan to deep red-brown, are formed primarily by *Thelephora terrestris* and/or *Laccaria laccata (sensu lato,* Fries and Mueller 1984), and were designated as Type 3 mycorrhizae. Many of the mycorrhizae have acquired a nearly black to deep jet-black color due to colonization by *Cenococcum graniforme*, an abundant mycorrhizal fungus in the original and surrounding hardwood forests, which were designated as Type 5 mycorrhizae. White to tan floccose forms are occasionally found, presumably colonized by *Boletus, Hebeloma, Paxillus* or *Suillus* spp., which have been designated as Type 6 mycorrhizae. Though variations occur within mycorrhizal morphology types, all fit within the grouping of these three main types described. A dissecting microscope was used, but was not always necessary, to distinguish the mycorrhizal types. Morphology types are tallied separately and then totaled for each seedling. Non-mycorrhizal root tips are easily distinguishable as white root tips composed entirely of plant tissue, obviously lacking a fungal component.

Descriptions of Red Pine Mycorrhizal Morphology Types

Type 3 Mycorrhiza

Macroscopic: Light buff to dark red brown, sometimes nearly black, usually lighter at the apex; 2-10 mm long x 0.25-1.0 mm diameter; mono- or bipodal, occasionally multiply bifurcated and in mass forming coralloid clusters; plump and straight when short, but spindly and often crooked when long, usually somewhat constricted at the base.

Microscopic: Surface hyphae sparse, 2-3 um diameter, bearing clamps, setae scattered, often clustered in bunches of 4-8, mostly 50-80 um long; mantle 10-20 um thick, thinner over apex, hyphae forming conspicuous interlocking, "jig-saw puzzle-like" pattern; cortical cells red-brown except over apex where they are colorless; Hartig net hyphae bulbous and also forming interlocking pattern.

Comments: This is the common and most numerous type of mycorrhiza found originally on the nursery red pine seedlings and which is still predominant. The causal fungi, as evidenced by cultural isolation, are most often *Laccaria laccata (sensu lato)* and *Thelephora terrestris*, though other fungi may also produce similar mycorrhizae. It is worth

noting that *L. laccata (sensu lato)* abounds in the surrounding forests and fruits abundantly on the plantation sites. This fungus might therefore be expected to maintain its dominance in the plantation seedlings. *Thelephora terrestris* has also been observed fruiting on the plantation sites.

Type 5 Mycorrhiza

Macroscopic: Black, sometimes with lighter apex; usually fuzzy with abundant attached, coarse hyphae; 1-3 mm long x 0.5-10 mm diameter; mono or bipodal, seldom multiply bifurcated; often appearing as if dark hyphae are enveloping Type 3 mycorrhizae.

Microscopic: Surface hyphae dark-brown to black, 3-6 um diameter, septate; setae arising from central stellate points of interlocking surface hyphae, setae 100 um or greater in length; mantle 10-30 um thick, mantle surface of coiled and interlocking hyphae; cortical cells dark and covered directly with hyphae of the same type observed with Type 3 mycorrhizae; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This is a later successional stage mycorrhiza, appearing as a dark sheath over an earlier developed mycorrhiza. The causal fungus is *Cenococcum graniforme*, which is commonly isolated from these mycorrhizae. Hypogeous fruit bodies of *Elaphomyces* sp., the anamorph of *C. graniforme*, have been collected in the surrounding forest, indicating that adequate inoculum is available.

Type 6 Mycorrhiza

Macroscopic: White to light gray-brown, mottled and silvery; 2-5 mm long x 0.5-1.0 mm diameter; abundant loosely-bound surface hyphae often binding soil matter; mono- or bipodal often in large coralloid clusters of multiply bifurcated tips; in water, air bubbles become entrapped in loose surface hyphae causing freed individual mycorrhizae to float.

Microscopic: Surface hyphae colorless, abundant, septate or not, 3-6 um diameter, multiply branched at septae; setae lacking; mantle of loose hyphae 24-100 um thick, cortical cells red-brown covered with interlocking hyphae similar to Type 3; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This also appears to be a later successional stage mycorrhiza type forming a sheath over an earlier developed mycorrhiza. Presumably the responsible fungi colonize new root tips as well. Based on cultural characteristics of isolated fungi, the causal fungi probably belong to the families Boletaceae, Cortinariaceae or Paxillaceae. Fruiting bodies of these families were common in the original forest and fruit abundantly in the surrounding forest, providing adequate and readily available inoculum.

Though red pine seedlings were outplanted on the study sites in June 1984, data from that year are not being compared with subsequent years for two reasons. First, 1984 was the year of plantation establishment; nursery seedlings are small and planting shock is known to have a significant effect on seedling root systems. Second, there are no ambient weather or soil data available for 1984 to use in covariate analysis. For years following 1984 site comparisons within and between years consider the parameters of non-mycorrhizal root tips per gram, Type 3 mycorrhizae per gram, Type 5 mycorrhizae per gram, Type 6 mycorrhizae per gram, and total mycorrhizae per gram of seedling root mass (o.d.w.). A significance level of $p=0.05$ with Duncan's Multiple Range Test was used to detect differences between means being tested. Comparisons among sites by month within years and among sites by years will be the primary focus of the statistical analysis. To facilitate this, mycorrhizae per gram of seedling root mass are further subjected to extensive analysis of covariance, with weather and soil variables applied as covariates.

Progress

Non-mycorrhizal root tips were not encountered in the 1988 season. Since 1985 nonmycorrhizal root tips have continued to decline, to the extent that in the previous year none were recorded for the final month at the Ground and Control sites, and for the last four months at the Antenna site. This steady decline in uncolonized root tips is likely a function of seedling maturation, and indicates that seedlings are becoming fully adapted to the native soil microflora. Non-mycorrhizal root tips remain a morphological type of interest, and should be watched for in future years, in case (hypothetically) seedlings undergo a reversion in maturity or establishment due to ELF field effects.

Type 3 mycorrhizae in 1988 continued to be the main mycorrhizal type on red pine seedling root systems at all sites. However, in 1988 there were generally fewer Type 3 mycorrhizae per gram of seedling root recorded for all months than in any previous year (Table 5.1). In 1988 there were three months when significant differences between sites occurred; in June the Ground site had fewer than the Control site, but did not differ significantly from the Antenna site; in September and October both the Ground and Antenna sites had fewer Type 3 mycorrhizae per gram than the Control site. Again, as in past years, indications are that the Control site tends to be more different from the other sites than the latter are from each other. This is possibly a reflection of greater soil moisture at the Control site.

Comparisons between years for any one site and month show that 1988 was the most unique thus far, with respect to the low numbers of Type 3 mycorrhizae recorded. Lower numbers of mycorrhizae per gram of root may be a function of aging seedlings, since this mycorrhizal type is known to be

Table 5.1. Mean and standard deviation of Type 3 mycorrhizae per gram of seedling root (o.d.w.) for red pine seedlings, 1985-1988.

	Ground		Antenna		Control	
Mo/Yr	$\bar{X}$1/	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 85	1052 c	680	1250 c	776	1030 c	652
86	1719 Ad	823	1611 Ac	892	2587 Bd	1439
87	1386 Acd	1002	1119 ABc	742	737 Bc	617
88	549 c	161	565 d	277	635 c	300
Jun 85	1284 c	700	880 c	405	846 c	742
86	1552 c	658	1500 d	578	1515 d	963
87	1830 c	1149	1755 d	1253	1079 cd	869
88	546 Ad	364	605 ABc	207	815 Bc	361
Jul 85	1326 Ac	966	1563 ABcd	1535	2403 Bc	1342
86	1763 c	922	1827 c	690	1657 d	684
87	1479 c	529	1101 de	522	1179 de	557
88	550 d	254	545 e	278	693 e	221
Aug 85	2527 c	985	2410 c	2139	2114 c	1147
86	1354 d	413	1247 d	663	1079 d	623
87	1372 Ad	339	916 Bd	305	963 Bd	522
88	552 Ae	277	510 Ad	250	902 Bd	440
Sep 85	3419 c	1453	3388 c	1533	2836 c	802
86	1066 d	752	875 d	386	679 d	439
87	493 de	272	719 d	491	880 d	678
88	351 Ae	311	359 Ad	113	619 Bd	440
Oct 85	2006 c	1144	2300 c	776	2665 c	1146
86	248 Ad	267	312 ABd	148	407 Bd	173
87	1066 Ae	509	678 Bd	381	913 ABd	356
88	425 d	271	390 e	193	464 e	341

1/ Site means with different upper case letters are significantly different from other sites for that month and year. Site means with different lower case letters are significantly different from other years for that site and month.

especially predominant on nursery stock. At the Ground site 1988 differed significantly from all other years for three of the six sampling months, June, July and August. At the Antenna site this was true for just one month, May. At the Control site, though lower numbers of Type 3 mycorrhizae were recorded for all months but October compared to other years for each respective month, any single month of 1988 was significantly related to at least one of the previous year's months. Perhaps the dry, hot weather of 1988 had a greater impact on the poorer, more rocky Ground site than on the more favorable sites, and this is evidenced by the greater differences detected there between this and previous years.

Type 5 mycorrhizae per gram of seedling root for 1988 were also generally fewer than any year since 1985 (Table 5.2). Sites were significantly different for three months; in May the Ground site had more Type 5 mycorrhizae per gram than the Control site, but did not differ from the Antenna site; in July the Antenna site had fewer Type 5 mycorrhizae per gram than the Control site , but did not differ from the Ground site; and in August the Antenna site had fewer Type 5 mycorrhizae per gram than both other sites. The slight indication is that fewer Type 5 mycorrhizae occurred on the Antenna site, and generally more occurred on both other sites. Four of six sampling months of 1988 the Control site had the highest number of Type 5 mycorrhizae recorded, though only twice, July and August, was it significantly higher from another site.

Statistical comparisons from year to year for any site and month demonstrate that 1988 was more like 1985 than other years, with respect to levels of Type 5 mycorrhizae. For the Ground site, 1988 was not significantly different from 1985 for four of the six sampling months; this was also the case for five months at both the Antenna and Control sites. In 1988 at the Ground site, for five of six months, number of Type 5 mycorrhizae per gram was neither significantly different from 1986 and 1987 as well; at the Antenna site this was true for two months, and for four months at the Control site. Thus, in spite of 1988 being most similar to 1985, it was also not significantly different from other years in any consistent pattern with regards to site or month to say that a decrease in this mycorrhizal type is occurring. As with Type 3 mycorrhizae it may be that age of seedlings and weather factors are causing this apparent reduction in these two most common mycorrhizal types.

Type 6 mycorrhizae are the least common type encountered on red pine seedling root systems on all of the study sites. They were first observed in late 1984 on very few seedlings. In 1985, Type 6 mycorrhizae were recorded only in July and August on the Control site. In 1986, no seedlings were found with Type 6 mycorrhizae. In 1987 the occurrence of Type 6 mycorrhizae was still infrequent and sporadic (Table 5.3), but they were found often enough on all sites (but not all months) to make comparisons between sites for the year. In 1988 the occurrence of Type 6 mycorrhizae was similar to the previous

Table 5.2. Mean and standard deviation of Type 5 mycorrhizae per gram of seedling root (o.d.w.) for red pine seedlings, 1985-1988.

	Ground		Antenna		Control	
Mo/Yr	$\bar{X}$[1/]	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 85	3 Ac	12	62 B	132	2 Ac	9
86	57 cd	117	126	149	168 d	187
87	158 e	103	144	116	183 d	168
88	98 Ade	100	54 AB	44	28 Bc	26
Jun 85	10 c	21	9 c	13	6 c	6
86	188 d	192	160 d	89	221 de	219
87	274 ABd	192	159 Bd	159	421 Ae	506
88	45 c	63	35 c	36	71 cd	60
Jul 85	19 c	23	26 c	37	8 c	11
86	135 d	153	200 d	209	170 c	233
87	145 Ad	118	203 Ad	157	425 Bd	456
88	89 ABcd	94	40 Ac	30	121 Bc	93
Aug 85	29 c	45	20 c	32	49 c	76
86	217 d	185	262 d	172	176 d	137
87	136 d	106	222 d	294	204 d	251
88	133 Ad	139	15 Bc	19	108 Acd	99
Sep 85	45 c	68	35 c	58	26 c	29
86	250 d	204	281 d	283	203 d	21
87	90 Ac	69	74 Ac	80	195 Bd	172
88	69 c	84	99 c	94	130 d	120
Oct 85	29 c	31	34 c	36	67	82
86	130 d	130	89 cd	57	93	69
87	150 d	104	146 d	159	141	137
88	89 cd	71	78 cd	142	116	129

[1/] Site means with different upper case letters are significantly different from other sites for that month and year. Site means with different lower case letters are significantly different from other years for that site and month.

Table 5.3. Mean and standard deviation of Type 6 mycorrhizae per gram of seedling root (o.d.w.) for red pine seedlings, 1987 and 1988.

	Ground		Antenna		Control	
Mo/Yr	$\bar{X}$[1/]	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 87	0	0	0	0	0	0
88	0 a	0	1 a	2	10	19
Jun 87	8	30	3	11	1	4
88	0	0	0	0	2	4
Jul 87	0	0	2	4	3	6
88	0	0	0	0	42	146
Aug 87	3 ab	5	0 a	0	11 b	20
88	17	39	13	38	15	56
Sep 87	0 a	0	0 a	0	13 b	22
88	0 a	0	61 b	132	6 ab	22
Oct 87	5	9	4	8	9	31
88	2	7	23	88	10	31

ab site means with different letters are significantly different from other site means for that month.

year, but higher numbers are being recorded, especially later in the season. In only two months of 1988 were differences between sites significant: in May the Ground and Antenna sites had lower numbers of Type 6 mycorrhizae per gram than the Control site, and in September the Ground site had lower numbers than the Antenna site while not differing from the Control site. Overall, Type 6 mycorrhizae are being encountered more regularly and in generally higher numbers at the Control site compared to the other sites. The Antenna site tends to be intermediate with respect to numbers of Type 6 mycorrhizae, and the Ground site leans towards having the fewest both in numbers and months encountered. This pattern may reflect site soil conditions, in a similar way as remarked upon above. This apparently later stage mycorrhizal type would be expected to develop sooner on the best of the sites, the Control site, where tree growth is advancing more quickly as well (see Element 2).

Many of the patterns seen regarding Type 3 mycorrhizae are also reflected in total mycorrhizae per gram of seedling root (Table 5.4). This is because Type 3 mycorrhizae constitute the majority of mycorrhizae occurring on the seedlings on the study sites. Generally, in 1988 fewer total mycorrhizae were counted per gram of seedling root than in previous years. There were four months where site differences were detected by analysis of variance. In June through September the Control site had significantly more mycorrhizae per gram of seedling root than one or both of the other sites. The Ground or Antenna site shared the feature of having the lowest total mycorrhizae per gram for those four months, though neither demonstrated this characteristic in any consistent manner. It is notable that there was never a month in 1988 when the Ground and Antenna site were significantly different from each other. Again, favorable soil factors are likely to be the reason why more mycorrhizae per unit of root mass occur on seedlings at the Control site.

Comparisons between years for any site bear out the observation that fewer mycorrhizae per gram of seedling root occurred in 1988 compared to other years. For the Ground site 1988 was significantly lower in this parameter from all other years for four of the six sampling months, these being May through August. For the Antenna site 1988 was significantly lower in total mycorrhizae per gram of seedling root from all other years for just two of the six sampling months, May and July. For the Control site 1988 was significantly lower in total mycorrhizae per gram of seedling root from all other years for but a single month, July. This pattern may indicate that the harsh weather conditions of 1988 were most easily ameliorated by the site with the greatest water capacity, the Control site, while having the most drastic effect on the site with the poorest soil conditions, the Ground site.

Table 5.4. Mean and standard deviation of total mycorrhizae per gram of seedling root (o.d.w.) for red pine seedlings, 1985-1988.

	Ground		Antenna		Control	
Mo/Yr	$\bar{X}$[1/]	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 85	1055 cd	676	1313 c	756	1033 c	650
86	1775 Ae	804	1737 Ac	915	2755 bd	1433
87	1544 de	1023	1263 c	745	920 c	588
88	647 c	185	619 d	285	673 c	313
Jun 85	1294 c	697	888 c	409	852 c	742
86	1740 cd	644	1660 d	597	1736 d	1002
87	2104 d	1226	1914 d	1274	1500 cd	1179
88	591 Ae	388	640 ABc	206	888 Bc	391
Jul 85	1351 Ac	976	1519 ABcd	1553	2411 bc	1342
86	1898 c	900	2027 d	739	1827 cd	745
87	1624 c	573	1306 c	548	1608 d	779
88	639 ABd	313	585 Ae	279	865 Be	313
Aug 85	2557 c	989	2429 c	2145	2163 c	1175
86	1571 d	432	1510 d	272	1256 d	690
87	1511 Ad	394	1188 ABde	629	915 Bd	400
88	703 Ae	350	538 Ae	260	1024 Bd	490
Sep 85	3464 c	1482	3423 c	1552	2861 c	800
86	1316 d	808	1156 d	604	882 d	446
87	583 Ae	291	793 ABd	482	1088 Bd	813
88	421 Ae	355	519 ABd	149	754 Bd	438
Oct 85	2035 c	1151	2334 c	786	2732 c	1166
86	379 d	311	401 e	163	500 d	160
87	1220 Ae	556	828 Bd	514	1062 ABe	336
88	516 d	320	490 de	263	590 de	475

1/ Site means with different upper case letters are significantly different from other sites for that month and year. Site means with different lower case letters are significantly different from other years for that site and month.

Covariate Analysis

The object of covariate analysis is to explain some of the differences in plantation seedling establishment between sites and years by taking into account the variation in ambient weather and soil conditions among sites and years. Ambient variables for all years were applied slightly differently in 1988 compared to 1987. This was done in order to fit the ambient variables more effectively to seedling root growth and mycorrhizal development. Last year, means and sums of ambient variables represented a period 30 days prior to each mycorrhizae sampling date. For the present report means and sums of ambient variables represent exactly the period between sampling dates, with only the first sampling date being represented by data gathered 30 days prior. This method of calculation eliminates any overlapping days occurring at the beginning or end of sampling periods whereby previously calculated ambient data would have been factored into both periods. Thus, this makes each set of ambient data unique with respect to period represented. The complete list of ambient variables used is shown in Table 5.5.

Correlations were performed to find which of the ambient variables were most likely to serve as covariates to explain observed variation in mycorrhizae per gram of seedling root among sites and years. Correlation coefficients (r) for mycorrhizae per gram of seedling root with the ambient variables are also shown in Table 5.5.

Analysis of variance (ANOVA) is performed with four years of data to detect differences between the various factors, and their interactions, on the seedling parameter of total mycorrhizae per gram of seedling root. Table 5.6, (top row, "no covariate") shows that no significant differences ($p<0.05$) occur among sites, months by site, and years by site. Significant differences for month and year are detected probably because these factors are time dependent and are related to seasonal and/or yearly growth fluctuation and establishment of newly planted seedlings as discussed above.

To test whether the addition of a covariate explained significant amounts of variation in the response variable an analysis of covariance (ANCOVA) was performed with the four years of collected data. Table 5.6 lists P values (significance of the F statistic) after analysis of covariance using the four significantly correlated ($p<.001$) ambient parameters individually as covariates. Changes upward of the P value decreases the difference for the factor being considered; for example, with no covariate the P value for site alone is .340; with mean minimum daily precipitation (PRCMNDAV) as a covariate the P value for site becomes .370. Thus, PRCMNDAV explained part of the variation between sites with respect to total mycorrhizae per gram of seedling root on those sites. PRCMNDAV as a covariate did not adjust the P value for other factors except month by site, which was decreased from .385 to .301, meaning it did not serve to explain differences here.

Table 5.5. Pearson correlation coefficients (r) calculated for total mycorrhizae per gram of seedling root with ambient parameters for the four years 1985 through 1988.

Ambient Parameter	Correlation Coefficient
AT=mean daily air temperature	.0135
ATMN=mean minimum daily air temperature	.0571
ATMX=mean maximum daily air temperature	-.0155
ATDD=mean air temperature degree days	.0158
ATDDRT=air temperature degree days running total	-.0513
ST5=mean soil temperature at 5 cm	.0327
ST5MN=mean minimum soil temperature at 5 cm	.0219
ST5MX=mean maximum soil temperature at 5 cm	.0525
ST5DD=mean soil temperature at 5 cm degree days	.0326
ST5DDRT=soil temperature at 5 cm degree days running total	-.0153
ST10=mean soil temperature at 10 cm	.0360
ST105MN=mean minimum soil temperature at 10 cm	.0394
ST10MX=mean maximum soil temperature at 10 cm	.0360
ST10DD=mean soil temperature at 10 cm degree days	.0360
ST10DDRT=soil temperature at 10 cm degree days running total	-.0142
PRCDAV=mean daily precipitation	.0474
PRCMNDAV=mean minimum daily precipitation	.2573*
PRCMXDAV=mean maximum daily precipitation	.0534
PRCTOT=total precipitation	.1466*
PRCRT=precipitation running total	.0546
PRC.01=number of days precipitation events > 0.01 cm	.1264*
PRC.10=number of days precipitation events > 0.10 cm	.1576*
SM5=mean soil moisture at 5 cm	.0095
SM5MN=mean minimum soil moisture at 5 cm	-.0278
SM5MX=mean maximum soil moisture at 5 cm	.0422
SM10=mean soil moisture at 10 cm	.0150
SM10MN=mean minimum soil moisture at 10 cm	.0751
SM10MX=mean maximum soil moisture at 10 cm	.0631

*Indicates significant correlation ($p<0.001$)

Table 5.6. Comparison of P values (significance of F) for total mycorrhizae per gram of seedling root data (1985 through 1988, all months, all sites) after multiple analysis of covariance (ANCOVA) using four significantly correlated (p<.001) ambient parameters individually as covariates.

COVARIATE	SITE	MONTH	MOxSITE	YEAR	YEARxSITE
No Covariate	.340	.001	.385	.000	.268
PRCMNDAV[1/]	.370	.001	.301	.000	.268
PRCTOT	.556	.001	.594	.000	.246
PR.01	.777	.001	.310	.000	.345
PR.10	.795	.000	.191	.001	.477

[1/]See Table 5.5 for key to abbreviations of ambient parameters.

The comparisons of greatest importance to our study are site, month by site and year by site, none of which show significant differences even with no covariate applied. Of the four ambient parameters used as covariates the one decreasing the site differences most is the number of days with precipitation events greater than .10 cm (PR.10); the ambient parameter decreasing month by site differences most is total precipitation (PRCTOT); the ambient parameter decreasing year by site differences most is again PR.10. These ambient parameters, calculated as described, are the most likely to be effecting seedling root growth and mycorrhizal development to the greatest degree, as identified by the methods of calculation used. However, other ambient parameters calculated in alternative ways warrant examination, and it is expected that P values for the respective factors can be elevated even more effectively than the examples given.

Summary

Multiple analysis of variance performed with the data collected from 1985 through 1988 from all sites and sampling dates indicates no significant differences between sites or years by site in mycorrhizae per unit weight of seedling root, causing us to accept the null hypothesis that there is no difference between ELF study sites in the abundance of mycorrhizae on plantation red pine seedlings. The use of several ambient parameter variables as covariates in the multiple analysis of covariance with total mycorrhizae per gram of seedling root reduces the difference between sites and years by sites considerably. Refinements of the analysis by finding more appropriate temporal relationships between the ambient data and other seedling growth parameters with seedling root growth and mycorrhizae development can be expected to further reduce differences among the sites.

Detection limits calculated with three years of data in 1987 indicated that an overall difference of approximately 10 to 15 percent would be necessary to recognize a significant difference among sites, and an overall difference of approximately 15 to 25 percent would be necessary to identify a significant difference among years by site. With refinements of the ambient parameters as mentioned above and their application to the analysis, recalculated detection limits are expected to be decreased as well. Findings thus far support the proposal that the mycorrhizal symbiosis between tree roots and fungi can indeed be used as a sensitive indicator of subtle environmental perturbation.

Element 6. LITTER PRODUCTION

Litter fall and decomposition is important in the transfer of nutrients and energy within a vegetative community. The sensitivity of foliage production to both tree physiological changes and non-independent external climatic conditions make it a good indicator of possible ELF field effects on trees. Since litter samples can be gathered at frequent intervals, they provide an estimate of change in canopy production. Additionally, leaf samples taken during the growing season for nutrient analysis and weight determination would monitor nutrient accumulation and subsequent nutrient translocation from the foliage to the branches prior to leaf fall. This physiological process is also sensitive to environmental stress and would be a potential indicator of ELF field effects.

The objective of this element is to obtain information on total litter weight and nutrient content, and foliar nutrient levels of northern red oak during the growing season on the antenna and control plots prior to the operation of the ELF communication system. Two overall null hypotheses will be tested in this study.

H_0: There is no difference in the total weight of litter fall (leaves, wood, and miscellaneous) before and after the ELF antenna becomes operational.

H_0: There is no difference in the foliar nutrient concentrations of northern red oak trees before and after the ELF antenna becomes operational.

Each year prior to an operational antenna (1984-1986), a baseline relationship of the ecological systems was determined whether there was any difference in the total weight of litter fall and foliar nutrient concentrations of northern red oak trees between the antenna and control site within a year.

The resulting ANOVA table for these analyses shown below (Table 6.1). Previous ELF annual reports have shown that no appreciable differences in these stand components were evident between these two sites prior to the onset of antenna operation.

Sampling and Data Collection

Five $1m^2$ meter litter traps are being used to monitor tree litter production on each permanent measurment plot at the antenna and the control sites. Litter was collected monthly during the summer and weekly after the onset of leaf fall in early September. Crown nutrient concentrations and translocation in northern red oak leaves are being examined by collecting foliage samples at both the antenna and control site during the summer months. An analysis of stem diameter data indicated that sampling trees of 15 cm, 21 cm and 32 cm

Table 6.1. ANOVA table for the analysis of litter components and foliar nutrients

Source of Variation	df	SS	MS	F
Plot	2	SS_P	MS_P	
$MS_P/MS_{E(S)}$				
Site	1	SS_S	MS_S	
$MS_Y/MS_{E(S)}$				
Error(s)	26	$SS_{E(S)}$	$MS_{E(S)}$	
Year	# years	SS_Y	MS_Y	
$MS_Y/MS_{E(Y)}$				
Site x year	(1)(#yrs-1)	SS_{SXY}		MS_{SXY}
$MS_{SXY}/MS_{E(Y)}$				

would adequately represent the distribution of red oak on each site. Three trees of each diameter were located adjacent to the permanent measurement plots at each site to minimize disturbance. Leaf samples were obtained from near the top of the crown using a 12 gauge shotgun with a full choke.

All litter and foliage samples were dried at 60°C in a forced draft oven. The litter was separated into leaves, wood, and miscellaneous categories and weighed. Leaf litter from a 0.25 m^2 compartment in each trap was separated by tree species. A representative subsample of ten leaves was taken from each foliage collection and weighed. All samples were ground to pass a 40 mesh sieve for subsequent N, P, K Ca and Mg analysis.

Progress

Litter weight

In 1988, the major litter fall in the ELF study area started between September 21 and September 28 and was completed by November 3 on both the antenna and control sites (Figure 6.1). This litter fall period began at a similar time as previous years but had the latest ending date thus far. (Figure 6.2a&b). As in past years, periodic litter fall amounts varied considerably between the antenna site and the control site at all collection times in the fall. These differences in weekly leaf fall are related to the variable tree species composition at each site. The leaf litter at the antenna site has a much higher proportion of red maple and big tooth aspen than the control site (Table 6.2). Oak leaves remain on the trees longer than the maple or aspen, and account for much of the litter fall variations between locations.

Figure 6.1.

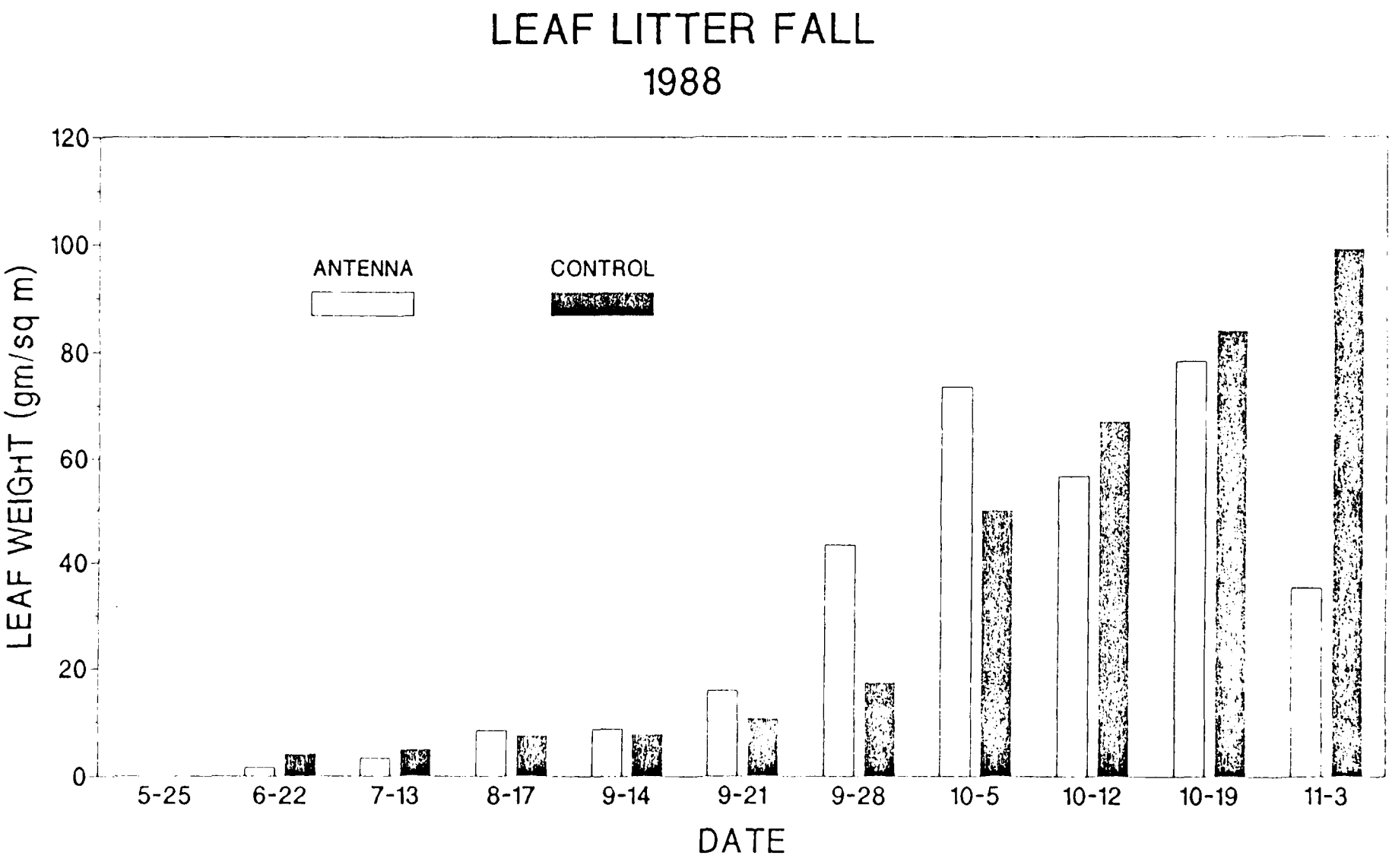

LEAF LITTER FALL
1988
LEAF WEIGHT (gm/sq m)
120
100
80
60
40
20
0
ANTENNA
CONTROL
5-25
6-22
7-13
8-17
9-14
9-21
9-28
10-5
10-12
10-19
11-3
DATE

Figure 6.2 a.

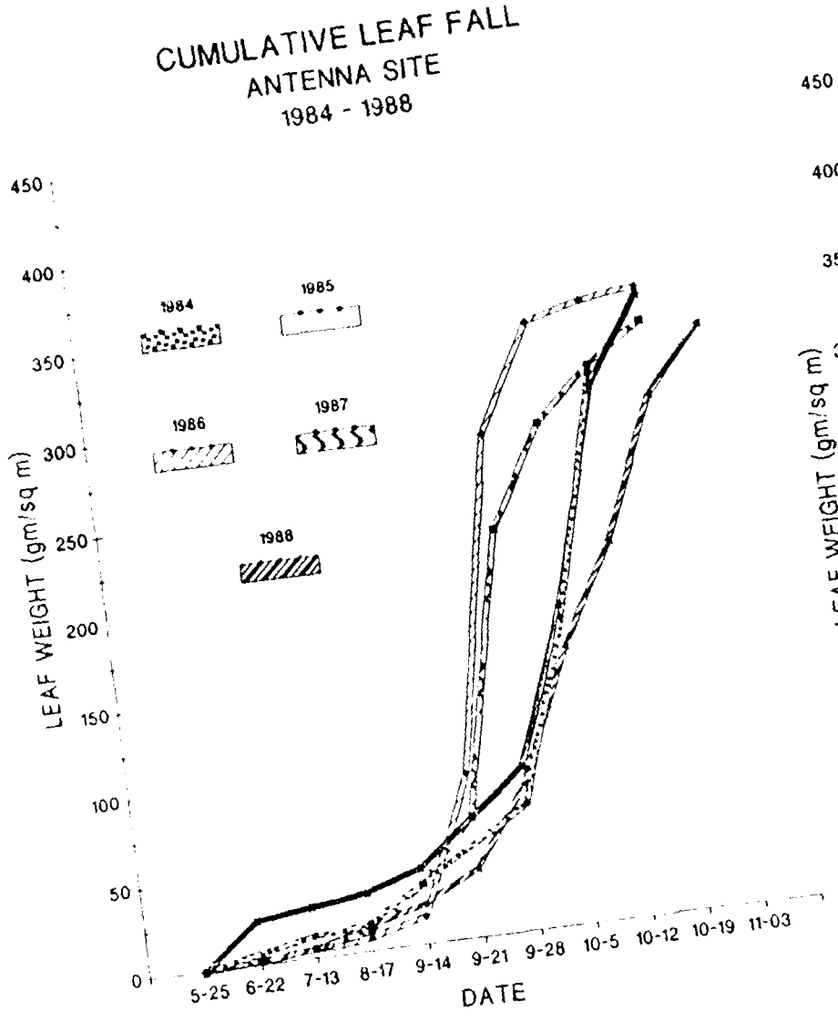


Figure 6.2 b.

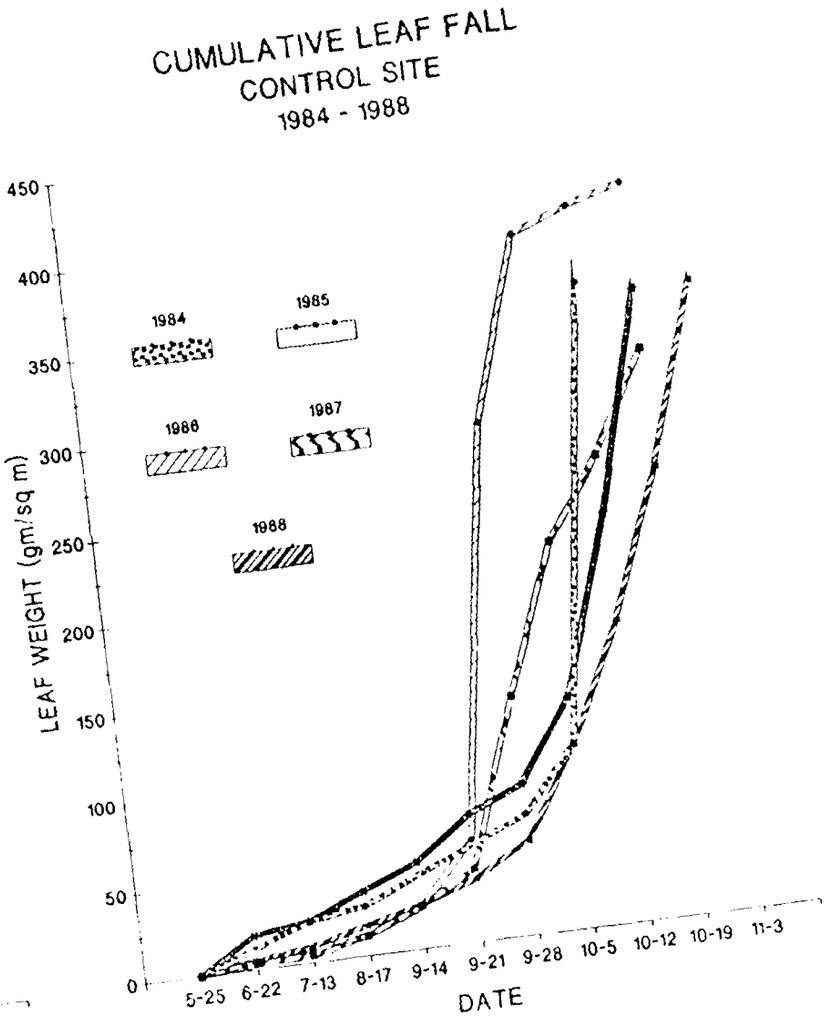


Table 6.2. Leaf litter fall by tree species at the antenna and control sites: 1985-1988.

Tree Species	Leaf Weight (g/m^2)				% of Total			
	1985	1986	1987	1988	1985	1986	1987	1988
Antenna								
Red Maple	135	147	142	143	45	43	44	41
Red Oak	93	120	105	116	31	35	33	33
Bigtooth Aspen	45	52	46	56	15	15	14	17
Quaking Aspen	1	1	2	3	<1	<1	<1	1
Paper Birch	25	21	25	28	9	6	8	8
Red Pine	1	1	2	2	<1	<1	<1	<1
Control								
Red Maple	42	55	47	41	14	17	16	13
Red Oak	227	226	208	208	73	69	69	71
Bigtooth Aspen	14	17	13	13	4	5	4	4
Quaking Aspen	11	9	8	8	3	3	3	4
Paper Birch	19	22	26	26	6	6	8	8
Red Pine	0	0	0	0	0	0	0	0

Analysis of variance (ANOVA) using the five year litterfall results showed significant site differences between both leaf and miscellaneous litter weights among years. While yearly differences in leaf litter weight have been found in earlier years, difference in miscellaneous litter this past year was due to a large acorn crop which resulted in double the average amount of miscellaneous litter (Table 6.3). The occurrence of significant differences in litter fall components among years would complicate the determination of possible ELF field effects after the antenna becomes fully operational. Thus, covariate analysis using stand and environmental variables that affect production was used to reduce litter fall variability among years, and improve detection limits between the antenna and control site.

Similar to past years, soil and air temperature generally showed the highest correlations with litter production and gave the best results when used in the analyses of covariance (Table 6.4). The use of these covariates reduced variability in litter fall among years to a non-significant level and further lowered the P values between sites (Table 6.5).

Results of these litter studies have shown that all three litter components could be used to study the effects of ELF fields on forest stands. However, the detection limits for differences in foliage litter among years and between sites are much lower than with the wood and the miscellaneous litter fraction (Table 6.6), and so would be a more sensitive indicator of possible ELF effects. Detectable differences in leaf litter improved from 11.6 to 9.9% of the mean with the addition of 1988 weights. Detectable differences in miscellaneous litter increased dramatically (from 33.3 to 62.3%) with the occurrence of the large acorn crop in 1988. This is to be expected since seed production is periodic, and is strongly influenced by temperature and precipitation (Kramer and Kozlowski, 1979). Given these limits and the results of the analysis of covariance, the lack of significance between the antenna and control sites for all three components indicate that the limited operational use of the ELF antenna in both 1987 and 1988 had no detectable effects on tree litter production.

Litter Nutrient Content

Total amounts of nutrients returned to the soil on each site reflect differences in site nutrient concentrations (Table 6.7). Average nutrient concentrations of the litter components for all tree species combined showed no site differences (Table 6.8 and 6.9). Covariate analysis using site and ambient factors listed in Table 6.10 was extremely useful in explaining differences in litter nutrient concentrations among sites and years. Most year and year by site differences were nonsignificant. However, significant differences in leaf Ca concentration between years, and year x site differences in leaf P concentrations would not be

Table 6.3. Total litter fall at the antenna and control sites: 1984-1988. Numbers in parentheses are standard deviations.

	Antenna	Control
	g/m^2	
Leaves		
1984	307 (66)	357 (102)
1985	347 (57)	352 (27)
1986	351 (49)	412 (87)
1987	332 (32)	319 (34)
1988	326 (45)	353 (53)
Average	332	358
Wood		
1984	44 (32)	54 (26)
1985	55 (31)	64 (33)
1986	43 (30)	58 (43)
1987	57 (38)	76 (38)
1988	53 (34)	62 (33)
Average	50	63
Miscellaneous		
1984	34 (24)	27 (14)
1985	52 (33)	45 (15)
1986	32 (8)	29 (11)
1987	33 (14)	28 (14)
1988	94 (64)	80 (35)
Average	49	42

Collection Period:
1984 - June 20, 1984 - Oct. 24, 1984
1985 - Oct. 25, 1984 - Oct. 23, 1985
1986 - Oct. 24, 1985 - Oct. 22, 1986
1987 - Oct. 23, 1986 - Oct. 21, 1987
1988 - Oct. 22, 1987 - Nov. 15, 1988

Table 6.4. Correlations between litter component weight and the covariates selected for inclusion in the analysis of covariance.

Covariate	Litter Component		
	Foliage	Wood	Miscellaneous
Soil Temperature Degree Days at 5 cm (August 16-September 15)	--	.14	--
Soil Temperature Degree Days at 10 cm (June 16-July 15)	--	.15	.67
Air Temperature Degree Days (June 16-August 15)	-.26	--	--
Air Temperature Degree Days (through July)	--	--	.54

Table 6.5 Significance levels from the split plot analysis of covariance for litter components - 1985 to 1988

Factor	Foliage	Wood	Miscellaneous
	p va[illegible]		
Site	0.86	0.90	0.50
Years	0.22	0.15	0.00
Site x Years	0.26	0.42	0.91

Table 6.6. Detection limits of litter component weights between treatment sites and between years.*

Litter Component	Sites		Years	
	g/m^2	%	g/m^2	%
Foliage	66.3	19.0	34.5	9.9
Wood	32.7	55.9	16.6	28.5
Miscellaneous	30.5	62.3	16.1	32.8

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

removed by covariate analyses. Similarly, there were no unexplained nutrient concentration differences between sites when leaf litter was separated by species, but year differences in oak P, oak Mg, and hazelnut and birch Ca levels were present. Also, significant year x site differences in oak P concentration were also found (Tables 6.11 and 6.12).

To further investigate these significant year and year by site interactions, SNK multiple range tests were performed using covariate adjusted means to evaluate whether nutrient concentrations had changed in response to ELF antenna operation in 1987 (Figure 6.3). The graphs show that in all cases, some significant differences existed between sites and years prior to the antenna. With most leaf litter nutrient concentration detection levels well below ten percent of the mean (Tables 6.13 and 6.14), these results suggests that there is no difference in litter nutrient concentrations that can be attributable to the low level ELF fields generated in 1987.

Foliage analyses

Analysis of nutrient concentrations in red oak foliage showed significant site differences in K levels, but these reflected the K status of the two sites before antenna transmissions began (Table 6.15). In addition, there were significant year by site differences for all nutrients, except Mg, that could not be explained using the current covariates under consideration (Table 6.16). Multiple range tests evaluating these differences showed that in all cases, significant year x site differences occurred prior to the

Table 6.7. Average nutrient content of litterfall at the antenna and control sites: 1985-1987.

	Antenna			Control		
	1985	1986	1987	1985	1986	1987
	(kg/ha)					
Foliage						
N	26.4	26.4	26.2	28.1	19.9	24.9
P	4.6	4.2	4.4	10.0	4.6	4.0
K	9.9	10.1	9.0	13.6	10.5	13.5
Ca	36.0	33.1	40.6	35.7	37.2	44.1
Mg	5.7	5.5	6.1	5.6	5.8	6.0
Wood						
N	3.2	2.7	2.3	0.4	3.3	2.7
P	0.3	0.3	0.2	4.0	0.4	0.2
K	0.5	0.4	0.3	0.9	0.8	.0.5
Ca	6.8	4.3	5.5	9.0	7.5	6.3
Mg	0.4	0.3	0.3	0.6	0.5	0.3
Miscellaneous						
N	7.1	3.4	12.3	5.1	3.7	6.6
P	0.8	0.3	1.3	0.9	0.3	0.7
K	2.8	1.0	1.9	1.6	0.7	1.4
Ca	3.0	2.0	8.8	5.6	3.1	9.9
Mg	0.5	0.3	1.0	0.4	0.2	0.7
Total						
N	36.7	32.5	40.8	37.2	26.9	24.2
P	5.7	4.8	5.9	11.3	5.3	4.9
K	13.2	11.5	11.2	16.1	12.0	15.4
Ca	45.8	39.4	54.9	50.3	47.8	60.3
Mg	6.6	6.1	7.4	6.6	6.5	7.0

Values in rows denoted by different letters are significantly different at the p=0.05 level.

Table 6.8. Average nutrient concentrations of litter components on the antenna and control sites: 1985-1987. Numbers in parentheses are standard deviations.

	Antenna (%)	Control (%)
Foliage		
N	0.78 (0.14)	0.71 (0.09)
P	0.13 (0.01)	0.18 (0.08)
K	0.29 (0.07)	0.37 (0.03)
Ca	1.09 (0.16)	1.14 (0.13)
Mg	0.17 (0.28)	0.17 (0.10)
Wood		
N	0.54 (0.10)	0.54 (0.14)
P	0.06 (0.01)	0.57 (0.02)
K	0.10 (0.05)	0.14 (0.06)
Ca	1.09 (0.19)	1.24 (0.24)
Mg	0.06 (0.01)	0.75 (0.19)
Miscellaneous		
N	1.24 (0.25)	1.08 (0.23)
P	0.13 (0.03)	0.14 (0.05)
K	0.34 (0.16)	0.26 (0.11)
Ca	0.72 (0.19)	1.19 (0.28)
Mg	0.10 (0.02)	0.09 (0.06)

Table 6.9. Average nutrient concentrations of tree litter on the antenna and control sites: 1985-1987. Numbers in parentheses are standard deviations.

	Antenna	Control
	(%)	
Northern Red Oak		
N	0.79 (0.20)	0.69 (0.06)
P	0.13 (0.02)	0.17 (0.07)
K	0.29 (0.05)	0.37 (0.02)
Ca	0.96 (0.05)	1.04 (0.08)
Mg	0.11 (0.01)	0.18 (0.02)
Paper Birch		
N	0.84 (.014)	0.81 (0.09)
P	0.14 (0.02)	0.18 (0.03)
K	0.38 (0.08)	0.48 (0.09)
Ca	1.44 (0.24)	1.56 (0.17)
Mg	0.27 (0.03)	0.21 (0.02)
Big Toothed Aspen		
N	0.75 (0.07)	0.68 (0.13)
P	0.10 (0.03)	0.14 (0.06)
K	0.32 (0.09)	0.47 (0.13)
Ca	1.36 (0.18)	1.20 (0.15)
Mg	0.26 (0.03)	0.19 (0.03)
Red Maple		
N	0.47 (0.05)	0.57 (0.11)
P	0.14 (0.02)	0.17 (0.03)
K	0.18 (0.07)	0.28 (0.08)
Ca	1.02 (0.08)	1.17 (0.06)
Mg	0.17 (0.01)	0.19 (0.01)

Table 6.10. Covariates used in covariate analyses of litter nutrient concentrations among sites and year.

Soil Nutrients in September	
Soil N	a
Soil P	b
Soil K	c
Soil Ca	d
Soil Mg	e
Air temperature degree days	
in September	f
in October	g
Air temperature degree days running total	
to the end of September	h
to the end of October	i
Air temperature	
in September	j
in October	k
Soil temperature at 5 cm	
in September	l
in October	m
Soil temperature at 10 cm	
in September	n
in October	o
Soil temperature degree days at 5 cm running total	
to the end of September	p
to the end of October	q
Soil temperature degree days at 10 cm	
in September	r
in October	s
Soil temperature degree days at 5 cm	
in September	t
in October	u

Table 6.11. Results of covariate analyses of site and year differences in litter component nutrient concentration.

	N	P	K	Ca	Mg
	p value				
Leaf	--	(c)*	--	(f)	(e)
Site	.118	.527	.116	.344	.368
Year	.672	.061	.766	.007	.068
Year x Site	.464	.000	.286	.704	.097
Wood	(ps)	(s)	(c)	(d)	(c)
Site	.811	.811	.159	.614	.901
Year	.999	.428	.280	.412	.639
Year x Site	.658	.914	.928	.582	.420
Miscellaneous	(cq)	(bc)	(h)	(dn)	(am)
Site	.231	.388	.301	.163	.203
Year	.326	.080	.146	.792	.201
Year x Site	.131	.105	.407	.657	.356

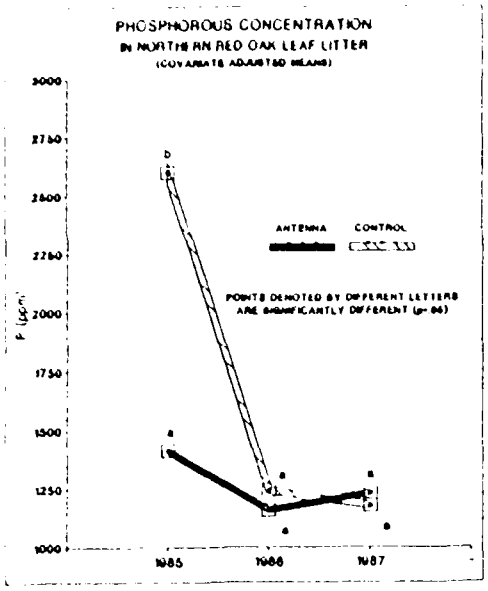
*Variables used in COANOVA (see Table 6.10).

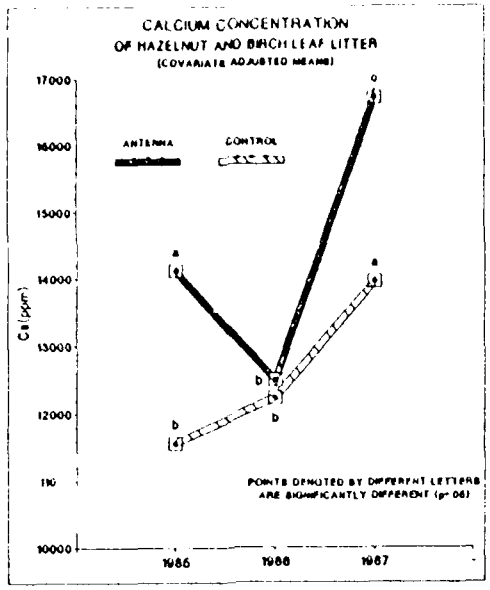
Table 6.12. Results of covariate analyses of site and year differences in leaf litter nutrient concentrations by species.

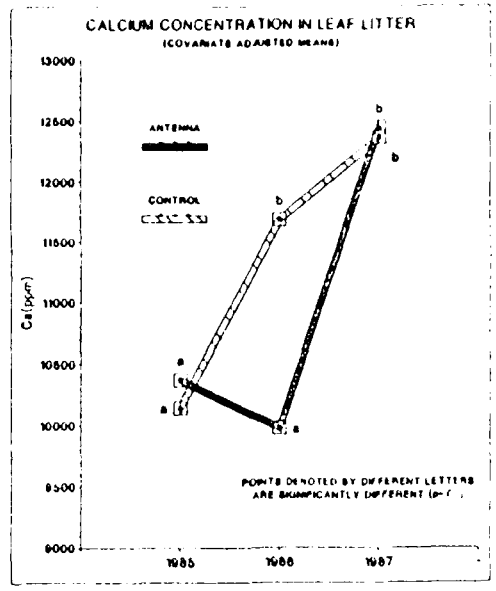
	N	P	K	Ca	Mg
	p value				
Northern Red Oak	--	(cf)	(cf)	(bh)	(ei)
Site	.338	.916	.385	.335	.096
Year	.157	.001	.887	.189	.040
Year x Site	.713	.000	.777	.464.	.066
Hazelnut and Paper Birch	(ab)	(cf)	(ah)	(kh)	(ah)
Site	.758	.852	.519	.582	.825
Year	.573	.361	.748	.007	.631
Year x Site	.601	.180	.534	.760	.431
Big Toothed Aspen	(bq)	(cde)	(dg)	(der)	(cdg)
Site	.472	.712	.356	.739	.151
Year	.720	.151	.107	.170	.097
Year x Site	.106	.066	.152	.702	.956
Red Maple	(cgh)	(l)	(ci)	(hit)	--
Site	.519	.624	.173	.235	.263
Year	.121	.087	.557	.909	.438
Year x Site	.504	.227	.660	.978	.374

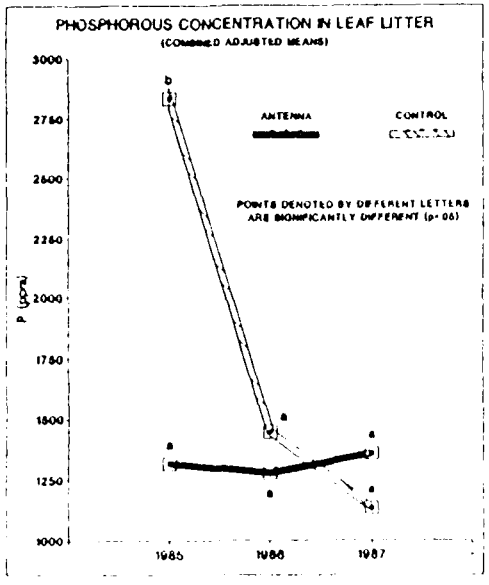
*Variables used in COANOVA (see Table 6.10.).

Figure 6.3.


PHOSPHOROUS CONCENTRATION
IN NORTHERN RED OAK LEAF LITTER
(COVARIATE ADJUSTED MEANS)
ANTENNA
CONTROL
POINTS DENOTED BY DIFFERENT LETTERS
ARE SIGNIFICANTLY DIFFERENT (p=.06)
1985
1986
1987


CALCIUM CONCENTRATION
OF HAZELNUT AND BIRCH LEAF LITTER
(COVARIATE ADJUSTED MEANS)
ANTENNA
CONTROL
POINTS DENOTED BY DIFFERENT LETTERS
ARE SIGNIFICANTLY DIFFERENT (p=.06)
1985
1986
1987


CALCIUM CONCENTRATION IN LEAF LITTER
(COVARIATE ADJUSTED MEANS)
ANTENNA
CONTROL
POINTS DENOTED BY DIFFERENT LETTERS
1985
1986
1987


PHOSPHOROUS CONCENTRATION IN LEAF LITTER
(COVARIATE ADJUSTED MEANS)
ANTENNA
CONTROL
POINTS DENOTED BY DIFFERENT LETTERS
ARE SIGNIFICANTLY DIFFERENT (p=.06)
1985
1986
1987

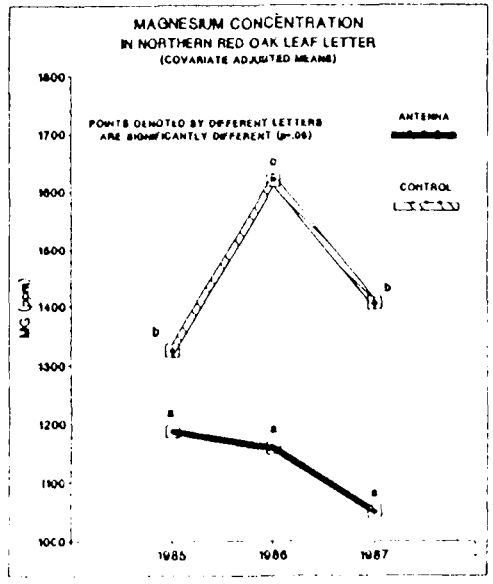

MAGNESIUM CONCENTRATION
IN NORTHERN RED OAK LEAF LETTER
(COVARIATE ADJUSTED MEANS)
POINTS DENOTED BY DIFFERENT LETTERS
ARE SIGNIFICANTLY DIFFERENT (p=.06)
ANTENNA
CONTROL
1985
1986
1987

Table 5.13. Detection limits for litter nutrient concentrations by component.*

Component	Site		Year	
	ppm	% of mean	ppm	% of mean
Leaf				
Ca	962	8.6	275	2.5
Mg	171	9.9	59	3.4
K	480	14.7	280	8.6
N	480	6.4	878	11.7
P	167	10.7	76	4.9
Wood				
Ca	650	4.8	330	2.8
Mg	75	10.8	91	13.2
K	161	13.7	278	23.7
N	656	12.1	777	14.3
P	79	14.0	89	15.8
Miscellaneous				
Ca	2025	21.4	1183	12.5
Mg	80	8.6	56	6.0
K	400	13.1	312	16.8
N	871	7.5	1319	11.4
P	173	13.0	104	7.8

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

Table 6.14. Detection limits for leaf litter nutrient concentrations by species.*

Species	Site		Year	
	ppm	% of mean	ppm	% of mean
Northern Red Oak				
N	1076	14.6	795	10.1
P	116	11.3	68	4.8
K	306	9.3	228	6.9
Ca	326	3.3	206	2.1
Mg	135	10.5	39	3.0
Hazelnut and Birch				
Ca	1574	11.6	352	2.6
Mg	245	8.9	107	3.9
K	403	9.4	307	7.1
N	831	10.0	341	4.1
P	193	11.9	116	7.2
Big Tooth Aspen				
Ca	1409	9.7	368	2.5
Mg	234	10.0	68	2.9
K	901	22.8	343	8.7
N	354	4.9	365	5.1
P	295	25.0	136	11.5
Red Maple				
Mg	118	6.5	73	4.0
Ca	414	3.7	454	4.1
K	220	9.6	269	11.8
N	435	8.8	298	6.0
P	130	8.3	119	7.6

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

Table 6.15. Northern Red Oak foliage nutrient concentration for antenna and control sites for 1985 to 1987.

	Antenna			Control		
	1985	1986	1987	1985	1986	1987
	(%)			(%)		
N	2.04	1.88	1.89	1.80	1.98	1.78
P	0.18	0.20	0.19	0.17	0.20	0.18
K	0.87	0.82	0.75	0.95	1.02	0.18
Ca	0.71	0.73	0.65	0.68	0.80	0.64
Mg	0.13	0.14	0.15	0.13	0.15	0.15

antenna operation in 1987 (Figure 4.). Using average leaf weight on a yearly basis may help to explain differences among years. Further work will examine this parameter as a covariate as leaf weight was significantly different by sampling date and may be responsible for differences in concentration (Table 6.17).

Because of the lack of good covariates in the analysis of foliage nutrient content at this time, detection limits are relatively high (Table 6.18). Detection limits are generally under ten percent for year differences but over ten percent for site differences. Thus, changes in tree nutrient translocation and cycling as affected by the ELF electromagnetic fields need to be relatively large to be detected by these analyses.

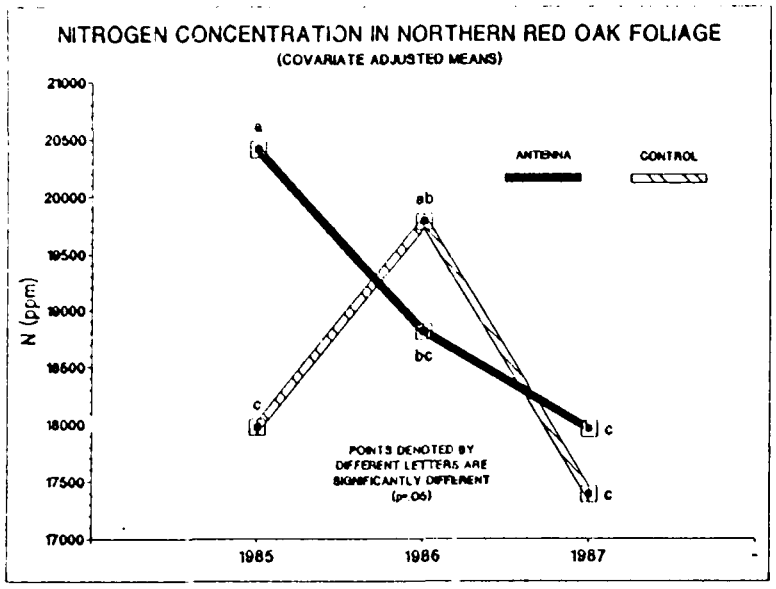
Table 6.16. Results of covariate analyses for differences in foliage nutrient concentration.

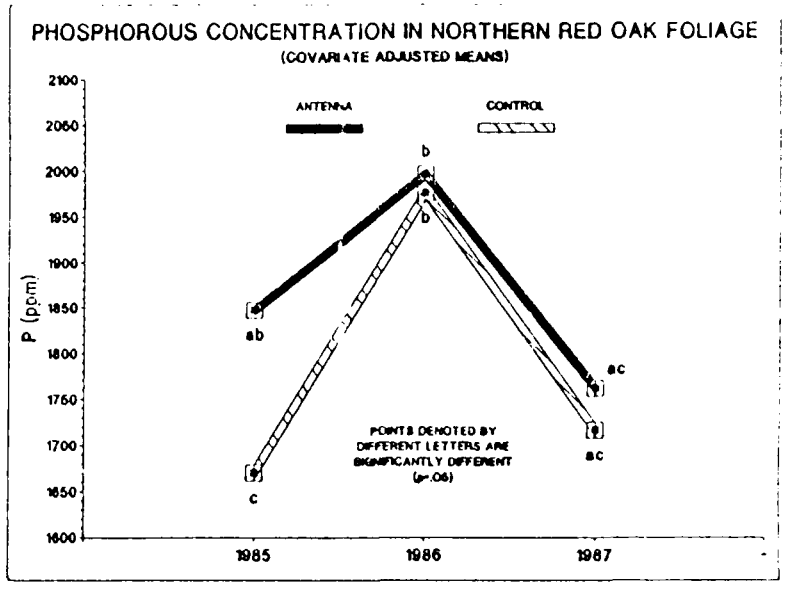
	N (1)*	P (2)	K (3)	Ca (4)	Mg (5)
	p values				
Site	.789	.275	.025	.921	.921
Tree Diameter	.391	.429	.006	.267	.056
Site x Diameter	.676	1.000	.008	.152	.164
Year	.078	.000	.000	.000	.642
Year x Site	.004	.161	.155	.096	.314
Year x Diameter	.843	.364	.100	.637	.247
Year x Site x Diameter	.231	.784	.247	.870	.432
Month	.000	.000	.000	.000	.000
Month x Site	.047	.089	.042	.440	.024
Month x Year	.000	.000	.000	.331	.058
Month x Year x Site	.280	.162	.072	.579	.425

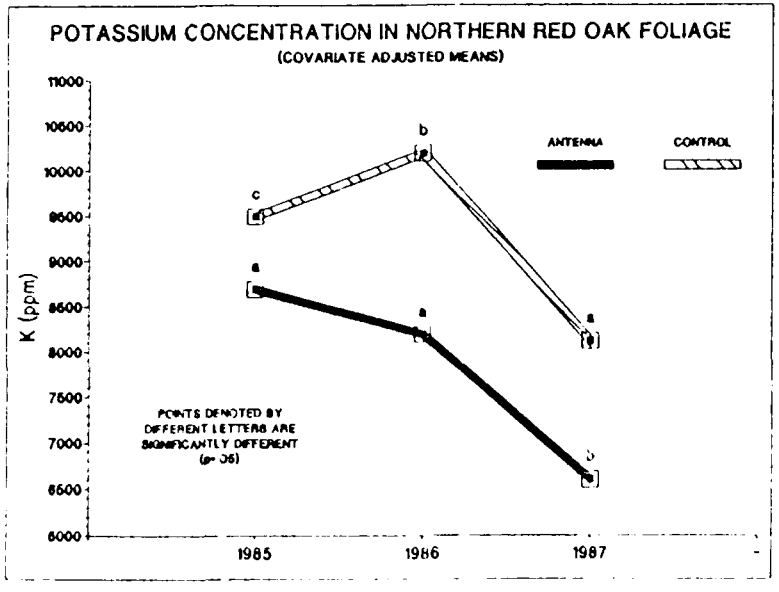
* Covariates used

[1] Soil temperature degree days at 10 cm
[2] Average maximum air temperature, soil moisture at 5 cm, soil temperature degree days at 5 cm
[3] Soil K and Mg, soil temperature degree days at 10 cm
[4] Average maximum air temperature, soil moisture at 10 cm, soil temperature degree days at 10 cm
[5] Air temperature degree days

Figure 6.4.


NITROGEN CONCENTRATION IN NORTHERN RED OAK FOLIAGE
(COVARIATE ADJUSTED MEANS)
N (ppm)
ANTENNA
CONTROL
POINTS DENOTED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT (p=.05)
1985
1986
1987


PHOSPHOROUS CONCENTRATION IN NORTHERN RED OAK FOLIAGE
(COVARIATE ADJUSTED MEANS)
P (ppm)
ANTENNA
CONTROL
POINTS DENOTED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT (p=.05)
1985
1986
1987


POTASSIUM CONCENTRATION IN NORTHERN RED OAK FOLIAGE
(COVARIATE ADJUSTED MEANS)
K (ppm)
ANTENNA
CONTROL
POINTS DENOTED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT (p=.05)
1985
1986
1987

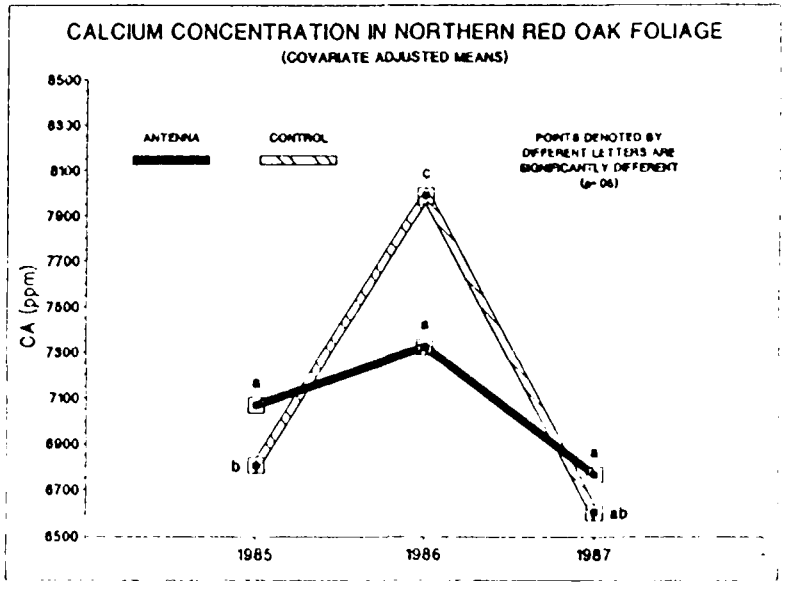

CALCIUM CONCENTRATION IN NORTHERN RED OAK FOLIAGE
(COVARIATE ADJUSTED MEANS)
CA (ppm)
ANTENNA
CONTROL
POINTS DENOTED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT (p=.05)
1985
1986
1987

Table 6.17. Analysis of variance results testing for differences in the average weight of ten leaf samples by site, tree diameter and sampling time.

	p value
Site	.937
Diameter	.474
Site x Diameter	.152
Year	.001
Year x Site	.492
Year x Diameter	.116
Year x Diameter x Site	.297
Month	.047
Month x Site	.504
Month x Year	.171
Month x Year x Site	.956

Table 6.18. Detection limits for Northern Red Oak foliage nutrient concentrations.*

	Site		Year	
	ppm	% of mean	ppm	% of mean
N	844	4.5	1532	8.2
P	228	15.2	177	9.7
K	1242	14.5	982	9.3
Ca	1684	23.7	792	11.1
Mg	342	22.5	108	7.5

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

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GLOSSARY

Ambient monitoring	Recording of existing climatic factors such as temperature, wind speed, precipitation, soil temperature and moisture, and solar radiation.
Basal area	The area of the cross section of a tree at DBH.
Biomass	The amount of living matter in a unit area.
Cambial activity	The wood building process of the tree cambium which results in increased diameter.
DBH	Diameter at breast height. Average stem diameter, outside bark, at a point 4.5 feet above the ground.
Dendrometer band	A permanent device placed on a tree for measuring diameter growth.
Ectomycorrhizae	A type of mycorrhizae in which the fungi grow only intercellularly and produce and external mantle.
Endomycorrhizae	A type of mycorrhizae in which the fungi penetrate the host root cells, but do not produce a mantle.
Habitat type	Land areas potentially capable of producing similar plant communities at maturity.
Herbaceous plant	A plant that does not produce persistent woody tissue.
Litter	Dead, unincorporated leaves, twigs, seeds, plant parts, etc. on the forest floor.
Mycorrhizae	An association between plant root tissues and fungal mycelia.
NESS	National Earth Satellite Service
NOAA	National Oceanographic and Atmospheric Administration
Phenology	The science concerned with periodic biological events in plants as related to environmental variables.

Phenophase	The timing of phenological events.
Species diversity	The number of different species and the amount of each in a given area.

UPLAND FLORA PUBLICATIONS AND PRESENTATIONS

Upland Flora Publications and Presentations

Becker, C.A. 1986. The effects of plant moisture stress on red pine (Pinus resinosa) seedling growth and establishment. M.S. Thesis, School of Forestry and Wood Products, Michigan Technological University, Houghton, Michigan.

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APPENDIX A

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616-3799

312/567-4000

29 December 1988

Dr. Glenn Mroz
Department of Forestry
Michigan Technical University
Houghton, MI 49931

Dear Dr. Mroz:

Enclosed is a floppy disk containing files of EM field data at your study sites as you requested. This data, which is comprehensive through 1988, is in both ASCII (.TXT) and Lotus (.WK1) formats. The ASCII files are those from Tables 3-11 in the 6 December 1988 letter that was sent to you. The Lotus files contain the same data as these ASC11 files but are organized differently.

The first page of Tables 3-11 (referenced above) is included to help clarify the nomenclature and organization of the files. In the upper left hand corner of these tables is written, the name of the ASCII file from which the table was printed and the name of the Lotus file which contains data, identical to that in the given table. Written at the head of each data column is the Lotus field name which contains this data.

The ASCII files are broken up by measurement condition (60 Hz, 76 Hz at actual operating currents, and 76 Hz extrapolation to a 150 ampere operating current) and by measurement type (transverse (air) electric field, longitudinal (earth) electric field, and magnetic flux) resulting in 9 separate files. The Lotus files are broken up only by measurement type resulting in 3 separate files. Field names are identical in the 3 Lotus files and provide measurement condition information. The measurement type is determined from the Lotus file name:

EA = transverse electric field
EE = longitudinal electric field
B = magnetic flux

Please contact me if I can be of further help.

Sincerely,

IIT RESEARCH INSTITUTE

David P. Haradem

David P. Haradem
Associate Engineer
(312) 567-4622

DPH:bjm
encl.

cc: JEZapotosky
JRGauger
RDCarlson/File

MA46088.TXT

MI4EA8.WK1

TABLE 3 60 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]	1988[c]
(LOTUS FIELD NAMES) →	EE6083	EE6084	EE6085	EE6086	EE6087	EE6088
4C1-6	-	0.003	-	-	-	-
4C1-7	-	0.006	-	-	-	-
4C1-8	-	0.004	-	-	-	-
4C1-9	-	0.002	-	-	-	-
4C1-10	-	-	-	-	-	-
4C1-11	-	-	-	-	-	-
4C1-12	-	-	-	-	-	-
4C1-13	-	-	-	-	-	-
4T2-3	-	0.001	-	-	-	0.002
4T2-4	-	-	-	-	-	0.001
4T2-5	-	-	-	-	-	0.011
4T2-6	-	-	-	-	-	<0.001
4T2-7	-	-	-	-	-	<0.001
4T2-8	-	-	-	-	-	--
4T2-9	-	-	-	-	-	-
4T2-10	-	-	-	-	-	-
4T2-11	-	-	-	-	-	-
4T2-12	-	-	-	-	-	--
4T2-13	-	-	-	-	-	<0.001
4T2-14	-	-	-	-	-	0.011

ME46088.TXT

MI4EE8.WK1

TABLE 4 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies

Site No., Meas. Pt.	a 1983	a 1984	a 1985	b 1986	c 1987	c 1988
(LOTUS FIELD NAMES) →	EE6083	EE6084	EE6085	EE6086	EE6087	EE6088
4C1-6	-	0.022	0.016	0.005	0.043	0.023
4C1-7	-	0.143	0.123	0.077	0.178	0.118
4C1-8	-	0.104	0.117	0.077	0.131	0.078
4C1-9	-	0.011	0.019	0.024	0.034	0.032
4C1-10	-	-	0.090	0.068	0.118	0.106
4C1-11	-	-	0.160	0.107	0.132	0.146
4C1-12	-	-	0.104	0.101	0.075	0.093
4C1-13	-	-	0.040	0.030	0.046	0.065
4T2-3	-	0.51	0.39	0.194	0.27	0.28
4T2-4	-	-	0.27	0.24	0.30	0.25
4T2-5	-	-	0.43	0.32	0.20	0.20
4T2-6	-	-	0.66	0.46	0.192	0.22
4T2-7	-	-	0.42	0.52	0.197	0.28
4T2-8	-	-	0.47	0.190	0.22	--
4T2-9	-	-	0.49	0.31	0.183	0.25
4T2-10	-	-	0.44	0.32	0.155	0.166
4T2-11	-	-	0.51	0.40	0.31	0.43
4T2-12	-	-	0.47	0.38	0.24	--
4T2-13	-	-	0.76	0.31	0.31	0.25
4T2-14	-	-	0.61	0.29	0.35	0.21

MB46088.TXT

MI4B8.WK1

TABLE 5 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies

Site No., Meas. Pt.	a 1983	a 1984	a 1985	b 1986	c 1987	c 1988
(LOTUS FIELD NAMES) →	EE6083	EE6084	EE6085	EE6086	EE6087	EE6088
4C1-6	-	0.003	0.003	0.003	0.002	0.003
4C1-7	-	0.003	0.002	0.001	0.003	0.002
4C1-8	-	0.003	0.003	0.002	0.003	0.002
4C1-9	-	0.003	0.003	0.002	0.001	0.002
4C1-10	-	-	0.002	0.002	0.002	0.002
4C1-11	-	-	0.002	0.002	0.002	0.002
4C1-12	-	-	0.002	0.003	0.001	0.002
4C1-13	-	-	0.002	0.003	0.001	0.003
4T2-3	-	0.002	0.001	0.001	0.003	0.005
4T2-4	-	-	0.001	0.001	0.003	0.006
4T2-5	-	-	0.001	0.007	0.017	0.030
4T2-6	-	-	0.001	0.006	0.006	0.014
4T2-7	-	-	0.001	0.004	0.004	0.007
4T2-8	-	-	0.001	0.002	0.004	--
4T2-9	-	-	0.001	0.003	0.003	0.005
4T2-10	-	-	0.001	0.003	0.003	0.005
4T2-11	-	-	0.001	0.004	0.005	0.007
4T2-12	-	-	0.002	0.004	0.005	--
4T2-13	-	-	0.001	0.005	0.008	0.013
4T2-14	-	-	0.002	0.011	0.018	0.029

MA4C08.TXT

MI4EA8.WK1

TABLE 6 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
Measured (M) and Extrapolated (Ex) Data

Site No., Meas. Pt.	1986 Exposures; Antenna Element, Current (Amps) NS(4) M	NEW(6) M	SEW(6) M	SEW(10) Ex	1987 Exposures; Antenna Element, Current (Amps) NS(15) M	EW(15) M	1988 Exposures; Antenna Element, Current (Amps) NS(75) M	EW(75) M
(LOTUS FIELD NAMES) →	E7NO46	E7NE66	E7SE66	E7SE106	E7NO157	E7EW157	E7NO758	E7EW758
4C1-6	-	-	-	--	-	-	-	-
4C1-7	-	-	-	--	-	-	-	-
4C1-8	-	-	-	--	-	-	-	-
4C1-9	-	-	-	--	-	-	-	-
4C1-10	-	-	-	--	-	-	-	-
4C1-11	-	-	-	--	-	-	-	-
4C1-12	-	-	-	--	-	-	-	-
4C1-13	-	-	-	--	-	-	-	-
4T2-3	-	-	0.004	0.007	0.002	0.014	0.006	0.125
4T2-4	-	-	0.005	0.008	0.001	0.014	0.017	0.113
4T2-5	0.018	-	0.092	0.153	0.003	0.23	0.033	2.6
4T2-6	-	-	0.005	0.008	0.003	0.013	0.014	0.142
4T2-7	-	-	0.007	0.012	0.001	0.018	0.020	0.165
4T2-8	-	-	0.004	0.007	0.002	0.012	--	--
4T2-9	-	-	0.005	0.008	0.002	0.010	0.019	0.137
4T2-10	-	-	0.004	0.007	0.002	0.011	0.020	0.112
4T2-11	-	-	0.003	0.005	0.002	0.012	0.010	0.130
4T2-12	-	-	0.002	0.003	0.002	0.014	--	--
4T2-13	-	-	0.005	0.008	0.002	0.012	0.010	0.121
4T2-14	0.030	-	0.155	0.26	0.003	0.186	0.026	2.5

ME4LOB.TXT

MI4EE8.WK1

TABLE 7 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
Measured (M) and Extrapolated (Ex) Data

Site No., Meas. Pt.	1986 Exposures; Antenna Element, Current (Amps) NS(4) M	NEW(6) M	SEW(6) M	SEW(10) Ex	1987 Exposures; Antenna Element, Current (Amps) NS(15) M	EW(15) M	1988 Exposures; Antenna Element, Current (Amps) NS(75) M	EW(75) M
(LOTUS FIELD NAMES) →	E7NO46	E7NE66	E7SE66	E7SE106	E7NO157	E7EW157	E7NO758	E7EW758
4C1-6	-	-	-	--	0.002	0.002	0.007	0.005
4C1-7	-	-	-	--	0.005	0.006	0.024	0.023
4C1-8	-	-	-	--	0.004	0.004	0.017	0.016
4C1-9	<0.001	<0.001	<0.001	--	0.002	0.002	0.007	0.006
4C1-10	-	-	-	--	0.005	0.004	0.026	0.023
4C1-11	-	-	-	--	0.006	0.005	0.028	0.028
4C1-12	-	-	-	--	0.004	0.003	0.016	0.016
4C1-13	-	-	-	--	0.002	0.002	0.012	0.011
4T2-3	1.31	0.22	6.3	10.5	1.36	15.2	7.7	76
4T2-4	1.05	0.22	5.0	8.3	1.70	10.7	6.2	68
4T2-5	1.18	0.24	5.3	8.8	1.46	12.7	8.2	62
4T2-6	1.11	0.27	4.4	7.3	2.2	12.4	10.4	56
4T2-7	1.13	0.23	5.3	8.8	1.31	9.7	8.8	71
4T2-8	1.32	0.25	5.7	9.5	1.81	15.8	--	--
4T2-9	1.17	0.21	5.1	8.5	1.46	13.7	7.1	63
4T2-10	0.97	0.22	4.1	6.8	1.84	10.5	8.1	50
4T2-11	1.14	0.21	5.0	8.3	2.2	10.7	9.6	122
4T2-12	1.06	0.21	4.3	7.2	1.93	13.5	--	--
4T2-13	1.12	0.64	5.4	9.0	1.74	14.9	8.2	71
4T2-14	1.07	0.175	5.1	8.5	1.66	14.3	6.6	56

MB4L08.TXT

MI4B8.WK1

TABLE 8 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
Measured (M) and Extrapolated (Ex) Data

Site No., Meas. Pt.	1986 Exposures; Antenna Element, Current (Amps) NS(4) M	NEW(6) M	SEW(6) M	SEW(10) Ex	1987 Exposures; Antenna Element, Current (Amps) NS(15) M	EW(15) M	1988 Exposures; Antenna Element, Current (Amps) NS(75) M	EW(7 M
(LOTUS FIELD NAMES) →	E7NO46	E7NE66	E7SE66	E7SE106	E7NO157	E7EW157	E7NO758	E7EW75
4C1-6	-	-	-	--	<0.001	<0.001	0.001	0.00
4C1-7	-	-	-	--	<0.001	<0.001	0.001	<0.00
4C1-8	-	-	-	--	<0.001	<0.001	0.001	<0.00
4C1-9	<0.001	<0.001	<0.001	--	<0.001	<0.001	0.001	0.00
4C1-10	-	-	-	--	<0.001	<0.001	0.001	<0.00
4C1-11	-	-	-	--	<0.001	<0.001	0.001	<0.00
4C1-12	-	-	-	--	<0.001	<0.001	0.001	<0.00
4C1-13	-	-	-	--	<0.001	<0.001	0.001	0.00
4T2-3	0.047	0.001	0.22	0.37	0.008	0.55	0.040	2.8
4T2-4	0.049	0.001	0.24	0.40	0.008	0.57	0.041	2.9
4T2-5	0.197	<0.001	1.00	1.67	0.011	2.4	0.061	12.4
4T2-6	0.058	0.001	0.44	0.73	0.006	1.16	0.020	5.0
4T2-7	0.046	0.001	0.22	0.37	0.006	0.59	0.024	2.6
4T2-8	0.045	0.001	0.22	0.37	0.006	0.59	--	--
4T2-9	0.029	0.001	0.138	0.23	0.007	0.38	0.027	1.72
4T2-10	0.033	0.001	0.149	0.25	0.006	0.39	0.027	1.78
4T2-11	0.043	0.001	0.21	0.35	0.006	0.56	0.025	2.6
4T2-12	0.047	0.001	0.23	0.38	0.006	0.61	--	--
4T2-13	0.086	<0.001	0.43	0.72	0.005	1.14	0.020	5.1
4T2-14	0.21	<0.001	1.03	1.72	0.012	2.5	0.061	11.9

MA4HI8.TXT

MI4EA8.WK1

TABLE 9 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
Data Extrapolated to 150 Ampere Current

Site No., Meas. Pt.	1986 Extrapolations NS	1986 Extrapolations NEW	1986 Extrapolations SEW	1987 Extrapolations NS	1987 Extrapolations EW	1988 Extrapolations NS	1988 Extrapolations EW
(LOTUS FIELD NAMES) →	E7NO1506	E7NE1506	E7SE1506	E7NO1507	E7EW1507	E7NO1508	E7EW1508
4C1-6	--	--	--	--	--	--	--
4C1-7	--	--	--	--	--	--	--
4C1-8	--	--	--	--	--	--	--
4C1-9	--	--	--	--	--	--	--
4C1-10	--	--	--	--	--	--	--
4C1-11	--	--	--	--	--	--	--
4C1-12	--	--	--	--	--	--	--
4C1-13	--	--	--	--	--	--	--
4T2-3	--	--	0.100	0.020	0.140	0.012	0.25
4T2-4	--	--	0.125	0.010	0.140	0.034	0.23
4T2-5	0.68	--	2.3	0.030	2.3	0.066	5.2
4T2-6	--	--	0.125	0.030	0.130	0.028	0.28
4T2-7	--	--	0.175	0.010	0.180	0.040	0.33
4T2-8	--	--	0.100	0.020	0.120	--	--
4T2-9	--	--	0.125	0.020	0.100	0.038	0.27
4T2-10	--	--	0.100	0.020	0.110	0.040	0.22
4T2-11	--	--	0.075	0.020	0.120	0.020	0.26
4T2-12	--	--	0.050	0.020	0.140	--	--
4T2-13	--	--	0.125	0.020	0.120	0.020	0.24
4T2-14	1.13	--	3.9	0.030	1.86	0.052	5.0

ME4HI8.TXT

MI4EE8.WK1

TABLE 10 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
Data Extrapolated to 150 Ampere Current

Site No., Meas. Pt.	1986 Extrapolations NS	NEW	SEW	1987 Extrapolations NS	EW	1988 Extrapolations NS	EW
(LOTUS FIELD NAMES) →	E7NO1506	E7NE1506	E7SE1506	E7NO1507	E7EW1507	E7NO1508	E7EW1508
4C1-6	--	--	--	0.020	0.020	0.014	0.010
4C1-7	--	--	--	0.050	0.060	0.048	0.046
4C1-8	--	--	--	0.040	0.040	0.034	0.032
4C1-9	--	--	--	0.020	0.020	0.014	0.012
4C1-10	--	--	--	0.050	0.040	0.052	0.046
4C1-11	--	--	--	0.060	0.050	0.056	0.056
4C1-12	--	--	--	0.040	0.030	0.032	0.032
4C1-13	--	--	--	0.020	0.020	0.024	0.022
4T2-3	49.	5.5	158.	13.6	152.	15.4	152
4T2-4	39.	5.5	125.	17.0	107.	12.4	136
4T2-5	44.	6.0	133.	14.6	127.	16.4	124
4T2-6	42.	6.8	110.	22.	124.	21	112
4T2-7	42.	5.8	133.	13.1	97.	17.6	142
4T2-8	50.	6.3	143.	18.1	158.	--	--
4T2-9	44.	5.3	128.	14.6	137.	14.2	126
4T2-10	36.	5.5	103.	18.4	105.	16.2	100
4T2-11	43.	5.3	125.	22.	107.	19.2	240
4T2-12	40.	5.3	108.	19.3	135.	--	--
4T2-13	42.	16.0	135.	17.4	149.	16.4	142
4T2-14	40.	4.4	128.	16.6	143.	13.2	112

MB4HI8.TXT

MI4B8.WK1

TABLE 11 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
Data Extrapolated to 150 Ampere Current

Site No., Meas. Pt.	1986 Extrapolations NS	1986 Extrapolations NEW	1986 Extrapolations SEW	1987 Extrapolations NS	1987 Extrapolations EW	1988 Extrapolations NS	1988 Extrapolations EW
(LOTUS FIELD NAMES) →	E7NO1506	E7NE1506	E7SE1506	E7NO1507	E7EW1507	E7NO1508	E7EW1508
4C1-6	--	--	--	--	--	0.002	0.002
4C1-7	--	--	--	--	--	0.002	--
4C1-8	--	--	--	--	--	0.002	--
4C1-9	--	--	--	--	--	0.002	0.002
4C1-10	--	--	--	--	--	0.002	--
4C1-11	--	--	--	--	--	0.002	--
4C1-12	--	--	--	--	--	0.002	--
4C1-13	--	--	--	--	--	0.002	0.002
4T2-3	1.76	0.025	5.5	0.080	5.5	0.080	5.6
4T2-4	1.84	0.025	6.0	0.080	5.7	0.082	5.8
4T2-5	7.4	--	25.	0.110	24.	0.122	25
4T2-6	2.2	0.025	11.0	0.060	11.6	0.040	10.0
4T2-7	1.73	0.025	5.5	0.060	5.9	0.048	5.2
4T2-8	1.69	0.025	5.5	0.060	5.9	--	--
4T2-9	1.09	0.025	3.5	0.070	3.8	0.054	3.4
4T2-10	1.24	0.025	3.7	0.060	3.9	0.054	3.6
4T2-11	1.61	0.025	5.3	0.060	5.6	0.050	5.2
4T2-12	1.76	0.025	5.8	0.060	6.1	--	--
4T2-13	3.2	--	10.8	0.050	11.4	0.040	10.2
4T2-14	7.9	--	26.	0.120	25.	0.122	24

APPENDIX B

Table 1 Missing data equations 1988.

1988 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
	Control Average Daily Air Temperature (Plantation)				
1	$Y = .954(X)$	15.5	.189	.982	Y±.37
2	$Y = 1.02(X)$	16.5	.192	.984	Y±.38
3	$Y = .943(X)$	14.9	.213	.980	Y±.42

X = average daily air temperature at Crystal Fall DNR station
Y = predicted average daily air temperature control plantation plots

	Control Average Daily Air Temperature (Hardwoods)				
1	$Y = .891(X)+1.57$	16.6	.222	.867	Y±.44
2	$Y = .868(X)+1.12$	14.9	.206	.855	Y±.41
3	$Y = .896(X)+.973$	15.5	.178	.874	Y±.35

X = average daily air temperature at Crystal Fall DNR station
Y = predicted average daily air temperature control hardwood plots

	Soil Temperature Control Plantation Plots (5 cm)				
1	$Y = 11.140(X_1)-.776(X_2)+.502(X_3)-30.06$	14.3	.097	.953	Y±.19
2	$Y = 13.739(X_1)-.940(X_2)+.451(X_3)-39.02$	13.9	.110	.943	Y±.22
3	$Y = 10.425(X_1)-.722(X_2)+.498(X_3)-27.40$	14.8	.093	.953	Y±.18

X_1 = month of year (i.e...6,7,8)
X_2 = month of year squared
X_3 = air temperature average control plantation plots
Y = predictd average daily soil temperature 5 cm on control plantation plots

	Soil Temperature Control Hardwood Plots (5 cm)				
1	$Y = 11.179(X_1)-.738(X_2)+.448(X_3)-33.21$	11.8	.090	.955	Y±.18
2	$Y = 9.989(X_1)-.650(X_2)+.481(X_3)-30.42$	12.1	.086	.949	Y±.17
3	$Y = 11.954(X_1)-.784(X_2)+.441(X_3)-36.68$	11.5	.111	.925	Y±.22

X_1 = month of year (i.e...6,7,8)
X_2 = month of year squared
X_3 = air temperature daily average control plantation plots
Y = plot average, daily soil temperature 5 cm on control hardwood plots

Table 2 Missing data equations 1988.

1988 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
Soil Temperature Control Plantation Plots (10 cm)					
1	$Y = 11.756(X_1) - .819(X_2) + .471(X_3) - 32.10$	13.8	.101	.948	Y±.20
2	$Y = 15.794(X_1) - 1.07(X_2) + .387(X_3) - 45.51$	13.7	.120	.932	Y±.24
3	$Y = 12.562(X_1) - .863(X_2) + .423(X_3) - 34.77$	13.8	.106	.938	Y±.21

X_1 = month of year (i.e...6,7,8)
X_2 = month of year squared
X_3 = average air temperature control plantation plots
Y = average daily soil temperature 10 cm on control plantation plots

Soil Temperature Control Hardwood Plots (10 cm)					
1	$Y = 12.982(X_1) - .856(X_2) + .335(X_3) - 38.44$	11.5	.102	.937	Y±.20
2	$Y = 13.355(X_1) - .884(X_2) + .324(X_3) - 39.25$	12.9	.141	.930	Y±.28
3	$Y = 11.904(X_1) - .774(X_2) + .332(X_3) - 35.92$	11.5	.095	.923	Y±.19

X_1 = month of year (i.e...6,7,8)
X_2= month of year squared
X_3 = air temperature daily average control plantation plots
Y = average daily soil temperature 10 cm on control hardwood plots

Soil Temperature Antenna Hardwood Plots (5 cm)					
1	$Y = .443(X_1) + .835(X_2) - 3.200$	11.6	.037	.988	Y±.07
2	$Y = -.256(X_1) + .921(X_2) + 0.434$	12.7	.074	.976	Y±.14
3	$Y = -.07(X_1) + .996(X_2) - 1.014$	12.3	.065	.975	Y±.13

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on ground site
Y = average daily soil temperature 5 cm on antenna hardwood plots

Table 3 Missing data equations 1988.

1988 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Antenna Plantation Plots (5 cm)				
1	$Y = .034(X_1)+1.002(X_2)-.604$	13.6	.054	.996	Y±.05
2	$Y = -.337(X_1)+1.078(X_2)+2.058$	14.6	.075	.983	Y±.15
3	$Y = -.158(X_1)+1.019(X_2)+1.309$	14.3	.028	.996	Y±.06

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on ground site
Y = average daily soil temperature 5 cm on antenna plantation plots

	Soil Temperature Antenna Hardwood Plots (10 cm)				
1	$Y = +.424(X_1)+.826(X_2)-3.107$	11.5	.039	.985	Y±.08
2	$Y = -.034(X_1)+.912(X_2)-.485$	12.0	.067	.965	Y±.13
3	$Y = -.057(X_1)+.963(X_2)-1.384$	11.6	.051	.981	Y±.10

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm on ground site
Y = average daily soil temperature 10 cm at antenna hardwood plots

	Soil Temperature Antenna Plantation Plots (10 cm)				
1	$Y =-.059(X_1)+1.017(X_2)-.462$	13.3	.022	.997	Y±.04
2	$Y = -.285(X_1)+1.106(X_2)+.882$	14.2	.034	.993	Y±.07
3	$Y = -.432(X_1)+1.128(X_2)+1.365$	13.9	.061	.981	Y±.12

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm on ground site
Y = average daily soil temperature 10 cm on antenna plantation plots

Table 4 Missing data equations 1988.

1988 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
Soil Moisture Antenna Plantation Plots (5 cm)					
1	$Y = -.394(X_1)+.942(X_2)+2.995$	11.3	.112	.837	Y±.22
2	$Y = -1.189(X_1)+.782(X_2)+8.652$	9.7	.182	.764	Y±.36
3	$Y = 1.080(X_1)+.747(X_2)-5.721$	11.0	.127	.842	Y±.25

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 5 cm on ground site
Y = average daily soil moisture 5 cm on antenna plantation plots

Soil Moisture Antenna Hardwood Plots (5 cm)					
1	$Y =-.118(X_1)+.753(X_2)-.969$	9.7	.408	.288	Y±.90
2	$Y = -1.090(X_1)+.876(X_2)+6790$	9.9	.161	.725	Y±.32
3	$Y = .280(X_1)+.914(X_2)-2.642$	10.2	.118	.838	Y±.23

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 5 cm on ground site
Y = average daily soil moisture 5 cm on antenna hardwood plots

Soil Moisture Antenna Plantation Plots (10 cm)					
1	$Y = .054(X_1)+.885(X_2)-1.771$	16.7	.159	.703	Y±.31
2	$Y = -.273(X_1)+.251(X_2)+7.646$	8.9	.106	.565	Y±.21
3	$Y = -.622(X_1)+.932(X_2)+2.369$	10.3	.132	.753	Y±.26

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 10 cm on ground site
Y = average daily soil moisture 10 cm on antenna plantation plots

Table 5 Missing data equations 1988.

1988 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
Soil Moisture Antenna Hardwood Plots (10 cm)					
1	$Y = .091(X_1)+.651(X_2)+1.5771$	10.9	.121	.714	Y±.24
2	$Y = -.260(X_1)+.796(X_2)+1.744$	10.5	.122	.747	Y±.24
3	$Y = -.450(X_1)+1.004(X2)+.924$	11.1	.204	.616	Y±.40

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 10 cm on ground site
Y = average daily soil moisture 10 cm on antenna plantation plots

Soil Temperature Ground Plantation Plots (5 cm)					
1	$Y = .348(X_1)+.965(X_2)-2.658$	13.5	.046	.987	Y±.09
2	$Y = .053(X_1)+.967(X_2)-.175$	13.9	.037	.992	Y±.07
3	$Y = .037(X_1)+.960(X_2)+.380$	14.2	.028	.995	Y±.06

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on antenna site
Y = average daily soil temperature 5 cm on ground site

Soil Temperature Ground Plantation Plots (10 cm)					
1	$Y = .469(X_1)+.896(X_2)-2.037$	13.7	.042	.987	Y±.08
2	$Y =-.125(X_1)+.951(X_2)+1.158$	13.5	.065	.986	Y±.13
3	$Y = .046(X_1)+.945(X_2)+.669$	14.0	.026	.996	Y±.05

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm on antenna site
Y = average daily soil temperature 10 cm on ground site

Table 6 Missing data equations 1988.

1988 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
Soil Moisture Ground Plantation Plots (5 cm)					
1	$Y = -.667(X_1)+1.144(X_2)+5.818$	13.7	.159	.849	Y±.31
2	$Y = -.521(X_1)+.990(X_2)+4.445$	11.8	.127	.779	Y±.25
3	$Y = .453(X_1)+1.021(X_2)-3.956$	10.8	.129	.842	Y±.25

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 5 cm on antenna site
Y = average daily soil moisture 5 cm on ground site

Soil Moisture Ground Plantation Plots (10 cm)					
1	$Y = 2.735(X_1)+2.588(X_2)-23.724$	12.7	.451	.708	Y±.88
2	$Y = .811(X_1)+.769(X_2)-1.208$	12.8	.086	.897	Y±.17
3	$Y = .687(X_1)+.849(X_2)-.759$	13.2	.116	.831	Y±.23

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 10 cm on antenna site
Y = average daily soil moisture 10 cm on ground site

Antenna Average Air Temperature (30 cm)					
	$Y = -.124(X_1)-.003(X_2)+1.048(X_3)+.590$	9.2	.017	.998	Y±.03

X_1 = month of year (i.e...6,7,8)
X_2 = month squared
X_3 = average daily air temperature control hardwood plots
Y = average daily air temperature (30 cm) antenna

Table 7 Missing data equations 1988.

1988 Missing Data Equations

Plot	Equation	$\bar{Y}$	Standard Error	R2	Confidence Interval at X1, X2
Relative Humidity Control Site					
	$Y = 3.095(X_1)-.019(X_2)-62.308$	76.9	1.121	.416	Y±0.83
	X_1 = month of year (i.e...6,7,8) X_2 = daily relative humidity at Crystal Falls DNR station Y = daily relative humidity at control site				
Control Average Air Temperature (30 cm)					
	$Y = 1.001(X_1)$	14.4	0.027	.999	Y±.053
	X_1 = average daily temperature at control hardwood stand Y = control average air temperature (30 cm)				
Total Daily Precipitation Control					
	$Y = 0.819(X_1)$	.068	0.012	.628	Y±.024
	X_1 = total daily precipitation at Crystal Falls DNR station Y = control total daily precipitation				

Table 8 Monthly ambient air temperatures, soil temperatures, and soil moistures

1988 GROWING SEASON	AIR TEMP. (deg. C.)	5 cm Soil TEMP. (deg. C)	5 cm Soil MOIST. (percent)	10 cm SOIL TEMP. (deg. C)	10 cm SOIL MOIST. (percent)
		GROUND SITE - PLANTATION			
APRIL	4.0	4.1	9.9	4.2	8.7
MAY	12.7	12.4	12.5	12.0	13.7
JUNE	17.1	17.5	7.8	17.1	9.4
JULY	19.6	19.7	10.4	19.1	10.1
AUGUST	17.3	19.0	15.3	19.1	15.1
SEPT.	12.3	13.7	14.7	14.2	17.1
OCT.	3.1	6.3	11.8	7.2	16.4
$\bar{X}$=	12.3	13.2	11.8	13.3	12.9
		ANTENNA SITE - PLANTATION			
APRIL	4.2	4.5	10.6	4.2	8.4
MAY	13.4	13.0	11.7	12.3	10.6
JUNE	17.9	18.0	7.3	17.4	6.6
JULY	20.6	20.3	9.2	19.8	9.0
AUGUST	18.4	19.2	13.9	19.0	12.8
SEPT.	12.5	13.7	13.8	13.6	13.2
OCT.	3.3	5.9	12.5	5.9	11.3
$\bar{X}$=	12.9	13.5	11.3	13.2	10.3
		ANTENNA SITE - HARDWOOD			
APRIL	4.3	2.8	8.9	2.0	7.6
MAY	13.3	10.3	10.7	9.7	11.6
JUNE	16.8	15.0	6.5	14.5	7.9
JULY	19.4	17.1	8.4	16.3	8.2
AUGUST	17.9	16.4	12.2	16.4	12.1
SEPT.	12.2	11.7	11.4	12.1	13.5
OCT.	3.4	4.9	8.6	6.0	12.7
$\bar{X}$=	12.5	11.2	9.5	11.0	10.5
		CONTROL SITE - PLANTATION			
APRIL	5.5	3.5	14.7	2.9	14.2
MAY	14.4	13.4	17.4	12.5	16.2
JUNE	18.8	18.7	10.0	18.1	11.8
JULY	21.1	20.3	7.3	19.9	8.0
AUGUST	19.3	19.5	14.9	19.1	15.8
SEPT.	13.6	14.2	14.9	13.9	18.5
OCT.	4.2	6.5	11.1	6.2	16.0
$\bar{X}$=	13.8	13.7	12.9	13.2	14.4
		CONTROL SITE - HARDWOOD			
APRIL	5.5	1.8	13.3	1.5	14.2
MAY	14.5	10.2	16.1	9.7	15.0
JUNE	18.3	14.8	10.2	14.4	9.8
JULY	20.2	17.4	6.1	16.7	6.8
AUGUST	18.3	17.6	9.8	17.0	12.4
SEPT.	12.8	13.0	9.6	13.0	16.0
OCT.	3.8	6.2	9.1	6.9	15.2
$\bar{X}$=	13.3	11.6	10.6	11.3	12.8

Table 9 Precipitation totals, solar radiation, air temperature (30 cm. above the ground), and relative humidity.

1988 GROWING SEASON	MONTHLY PRECIPITATION (in.)	SOLAR RADIATION	AIR TEMP. 30 CM. (deg. C.)	RELATIVE HUMIDITY (percent)
		GROUND SITE		
APRIL	.27			63.2
MAY	1.17	538.4 (Langley/		65.2
JUNE	.78	509.6 Day)		69.7
JULY	3.22	542.8		75.9
AUGUST	6.81	133.1		90.6
SEPT.	4.14	297.3		89.2
OCT.	3.50	178.1		89.3
TOTAL=	19.89 $\bar{X}$	365.6		77.2
		ANTENNA SITE		
APRIL	.27	14.7 (Eins.	3.9	63.2
MAY	1.25	15.7 /Day)	13.4	65.2
JUNE	.74	1.9	16.6	69.7
JULY	3.01	.7	18.9	75.9
AUGUST	6.63	.2	17.4	90.6
SEPT.	4.07	.2	11.8	89.2
OCT.	3.50	2.5	2.8	89.3
TOTAL=	19.47 $\bar{X}$	5.1	12.1	77.2
		CONTROL SITE		
APRIL	.87	28.7	5.5	53.4
MAY	.69	12.7	14.5	55.9
JUNE	2.30	.7	18.3	61.3
JULY	2.07	.1	20.3	62.1
AUGUST	4.83		18.5	62.6
SEPT.	3.12		12.8	60.9
OCT.	2.55		3.7	72.0
TOTAL=	16.43 $\bar{X}$	10.6	13.4	60.8

Table 10. Mean soil nutrient values (kg/ha)Hardwoods 1985-1987

ANTENNA

	1985					1986					1987				
	Ca	Mg	K	P[a]	N	Ca	Mg	K	P[b]	N	Ca	Mg	K	P[b]	N
May	433.79	56.09	54.98	2.71	1193.57	-	-	-	-	-	264.99	44.03	49.79	617.66	1046.31
Jun	545.04	71.58	67.67	2.63	1672.95	310.01	50.62	48.69	1132.92	564.56	176.20	42.57	36.25	613.01	1492.42
Jul	459.66	67.96	70.91	3.00	1290.39	246.89	52.93	39.22	1303.99	542.35	162.18	27.56	52.55	597.86	978.10
Aug	466.99	56.72	53.50	2.52	900.67	211.37	44.84	45.00	944.21	537.81	164.24	34.33	39.22	644.44	879.63
Sep	445.95	55.45	56.51	1.83	868.69	221.70	43.61	40.23	965.75	456.09	163.80	35.20	40.52	569.24	1023.40
Oct	432.36	54.15	58.86	2.78	1214.97	-	-	-	-	-					

CONTROL

	1985					1986					1987				
	Ca	Mg	K	P[a]	N	Ca	Mg	K	P[b]	N	Ca	Mg	K	P[b]	N
May	681.04	94.50	71.06	2.17	1384.12	-	-	-	-	-	601.69	82.94	82.44	740.53	1494.04
Jun	683.10	83.34	79.49	2.47	1282.08	336.80	41.89	60.53	982.53	746.19	285.93	54.12	41.77	696.56	1081.69
Jul	904.92	107.00	114.41	4.59	1701.63	371.76	86.08	49.59	1005.18	770.28	295.83	39.95	55.12	720.62	896.95
Aug	698.71	77.54	77.14	2.61	1037.65	398.40	160.14	45.82	923.25	704.46	305.23	51.43	43.88	688.24	978.14
Sep	519.04	64.97	71.35	2.22	966.23	402.91	81.42	57.02	1091.92	664.56	377.66	53.99	50.46	777.02	1014.04
Oct	566.70	76.03	70.52	2.76	1201.93	-	-	-	-	-					

[a] Water soluble P
[b] Total P

Table 11. Mean soil nutrient values (kg/ha) Plantations 1985-1987

GROUND

	1985					1986					1987				
	Ca	Mg	K	P[a]	N	Ca	Mg	K	P[b]	N	Ca	Mg	K	P[b]	N
May	-	-	-	-	-	-	-	-	-	-	450.51	65.06	66.71	495.95	1059.76
Jun	-	-	-	-	-	438.97	68.04	66.19	1439.19	520.07	401.64	67.45	57.74	476.77	1132.84
Jul	1058.32	120.45	118.91	3.53	1869.81	393.43	68.11	70.88	1159.94	523.75	433.26	56.08	119.09	472.77	928.65
Aug	-	-	-	-	-	479.76	68.89	57.89	845.06	501.93	242.93	45.42	50.01	502.39	722.00
Sep	-	-	-	-	-	583.92	79.02	65.69	1168.39	454.77	362.81	51.67	47.37	430.52	1040.38

ANTENNA

	1985					1986					1987				
	Ca	Mg	K	P[a]	N	Ca	Mg	K	P[b]	N	Ca	Mg	K	P[b]	N
May	-	-	-	-	-	-	-	-	-	-	434.78	59.50	68.62	633.37	1220.57
Jun	-	-	-	-	-	339.10	42.18	49.98	1171.12	667.71	356.22	55.81	40.14	580.07	1848.89
Jul	637.70	82.02	89.76	3.85	1539.19	326.02	60.57	50.41	1195.71	658.81	277.70	29.85	46.01	633.38	833.67
Aug	-	-	-	-	-	233.15	35.13	43.39	929.81	679.29	264.88	35.93	39.66	753.05	998.80
Sep	-	-	-	-	-	515.17	67.05	64.00	1138.27	620.12	275.97	38.13	46.14	619.82	836.46

CONTROL

	1985					1986					1987				
	Ca	Mg	K	P[a]	N	Ca	Mg	K	P[b]	N	Ca	Mg	K	P[b]	N
May	-	-	-	-	-	-	-	-	-	-	885.37	93.98	109.12	693.03	1465.86
Jun	-	-	-	-	-	456.21	48.27	77.38	1141.23	713.35	760.34	88.02	58.27	730.08	1245.42
Jul	1051.32	112.44	101.94	3.27	1853.58	478.55	68.99	56.50	1138.57	730.90	616.87	53.36	78.20	758.08	1043.89
Aug	-	-	-	-	-	558.00	76.77	56.62	858.73	673.86	501.45	61.07	62.91	741.97	874.30
Sep	-	-	-	-	-	655.21	76.33	73.32	1175.67	844.44	616.92	66.53	60.78	744.44	1053.35

[a] Water soluble P
[b] Total P

APPENDIX C

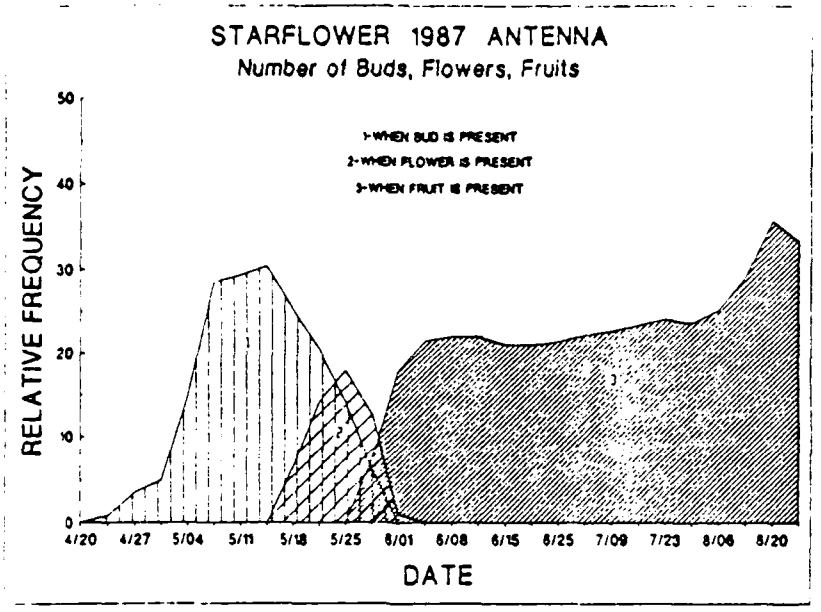
Average plant moisture stress values 1985-1988 (-MPa). N=15.

	1985			1986		
Week of	Ground	Antenna	Control	Ground	Antenna	Control
5/25	2.32	2.17	1.10	.68	.77	.70
6/10	--	--	--	.62	.68	.80
6/24	.50	.50	.64	.73	.86	.74
7/8	--	--	--	.66	.72	.74
7/22	.63	.65	.68	.59	.63	.93
8/5	--	--	--	.45	.46	.62
8/19	.59	.57	.64	.37	.39	.56
9/2	--	--	--	.39	.36	.47
9/20	1.94	2.15	2.25	--	--	--

	1987			1988		
Week of	Ground	Antenna	Control	Ground	Antenna	Control
5/25	.23	.26	.24	.59	.52	.45
6/10	.19	.20	.19	.28	.21	.32
6/24	.23	.15	.24	.53	.38	.40
7/8	.26	.26	.50	.57	.41	.52
7/22	.25	.19	.21	.67	.47	.69
8/5	.42	.27	.43	.27	.23	.39
8/19	.54	.66	.43	.24	.35	.28
9/2	.81	.65	.75	.35	.45	.66
9/20	.77	.69	.62	--	--	--

Note: Xylem water was frozen during the weeks of 5/25 and 9/20 1985 which results in artificially high PMS values.

APPENDIX D


STARFLOWER 1987 ANTENNA
Number of Buds, Flowers, Fruits
1-WHEN BUD IS PRESENT
2-WHEN FLOWER IS PRESENT
3-WHEN FRUIT IS PRESENT
RELATIVE FREQUENCY
0
10
20
30
40
50
4/20
4/27
5/04
5/11
5/18
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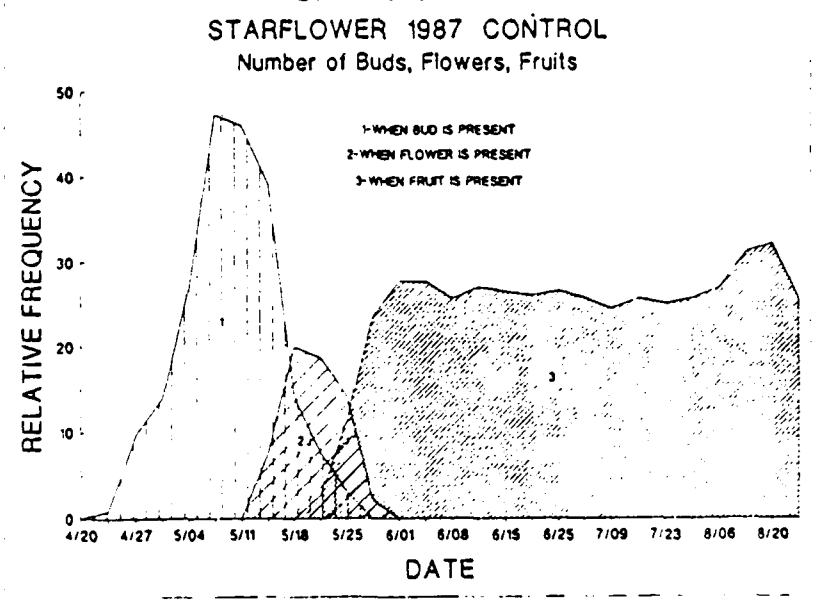
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Number of Buds, Flowers, Fruits
1-WHEN BUD IS PRESENT
2-WHEN FLOWER IS PRESENT
3-WHEN FRUIT IS PRESENT
RELATIVE FREQUENCY
0
10
20
30
40
50
4/20
4/27
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8/06
8/20
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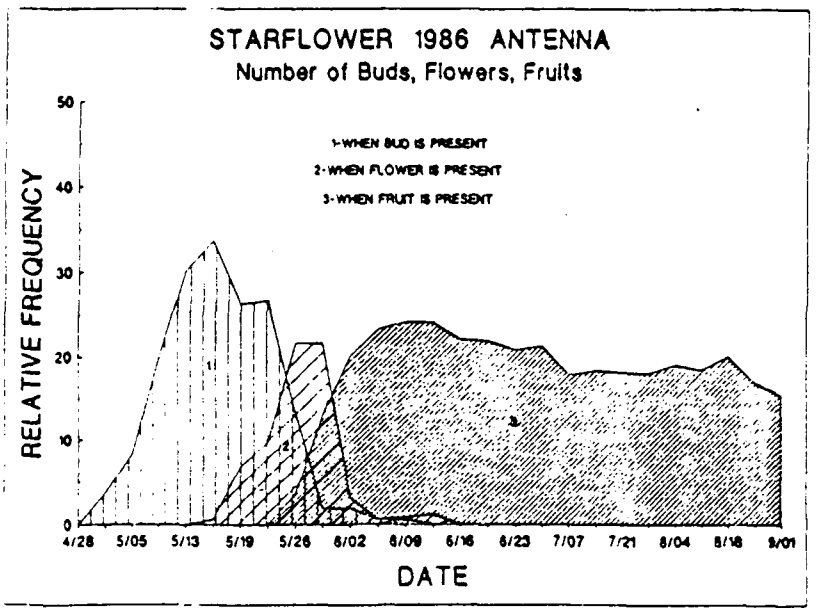
STARFLOWER 1986 ANTENNA
Number of Buds, Flowers, Fruits
1-WHEN BUD IS PRESENT
2-WHEN FLOWER IS PRESENT
3-WHEN FRUIT IS PRESENT
RELATIVE FREQUENCY
50
40
30
20
10
0
4/28
5/05
5/13
5/19
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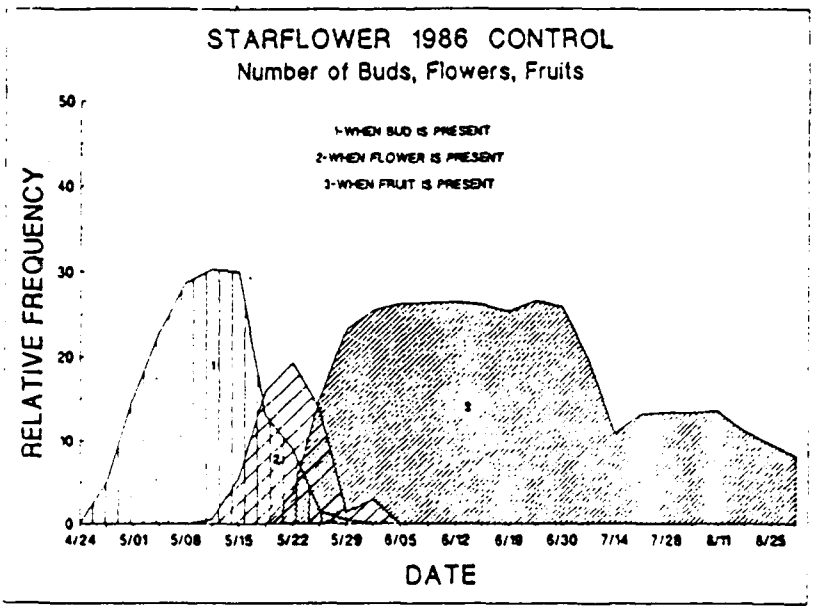
STARFLOWER 1986 CONTROL
Number of Buds, Flowers, Fruits
1-WHEN BUD IS PRESENT
2-WHEN FLOWER IS PRESENT
3-WHEN FRUIT IS PRESENT
RELATIVE FREQUENCY
50
40
30
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10
0
4/24
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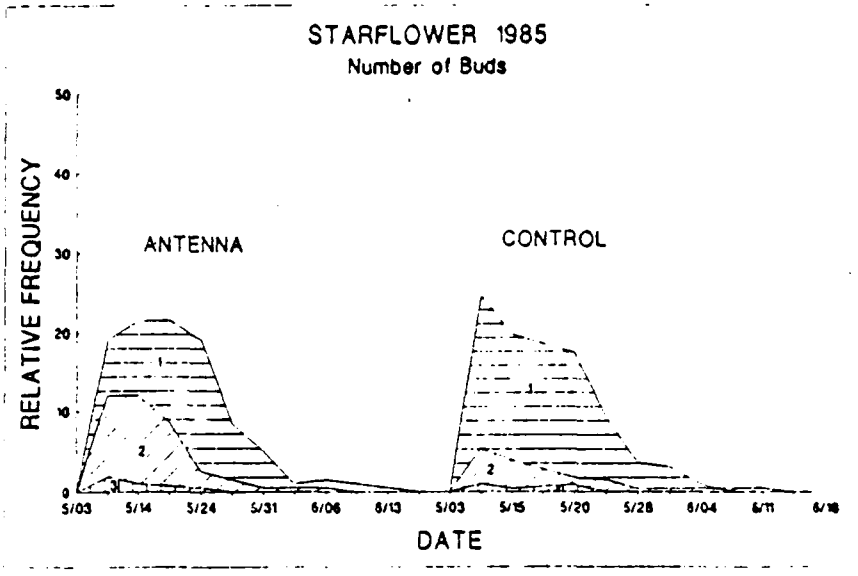
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Number of Buds
RELATIVE FREQUENCY
ANTENNA
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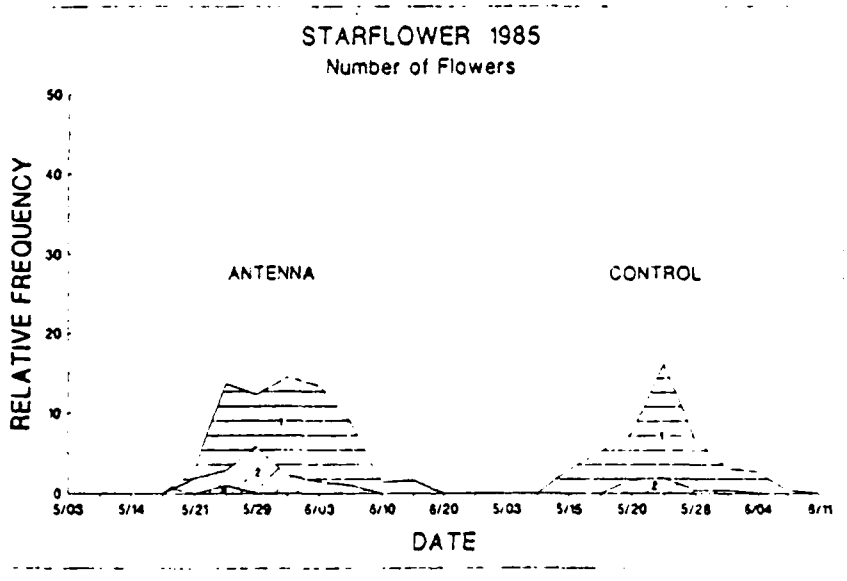
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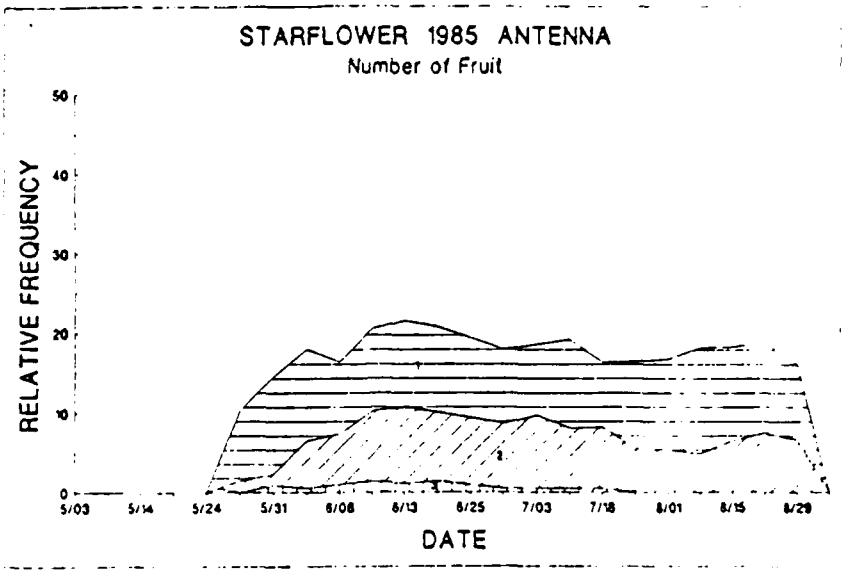
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Number of Fruit
RELATIVE FREQUENCY
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40
30
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10
0
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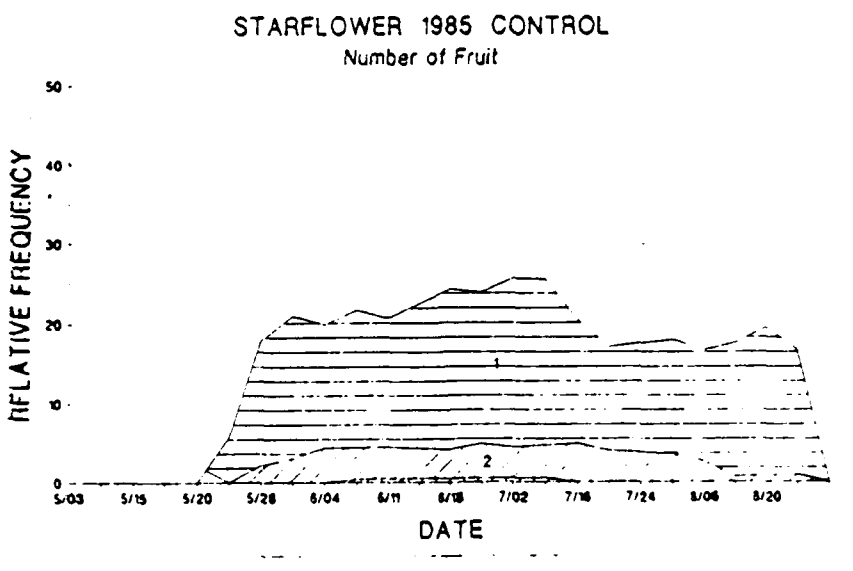
STARFLOWER 1985 CONTROL
Number of Fruit
RELATIVE FREQUENCY
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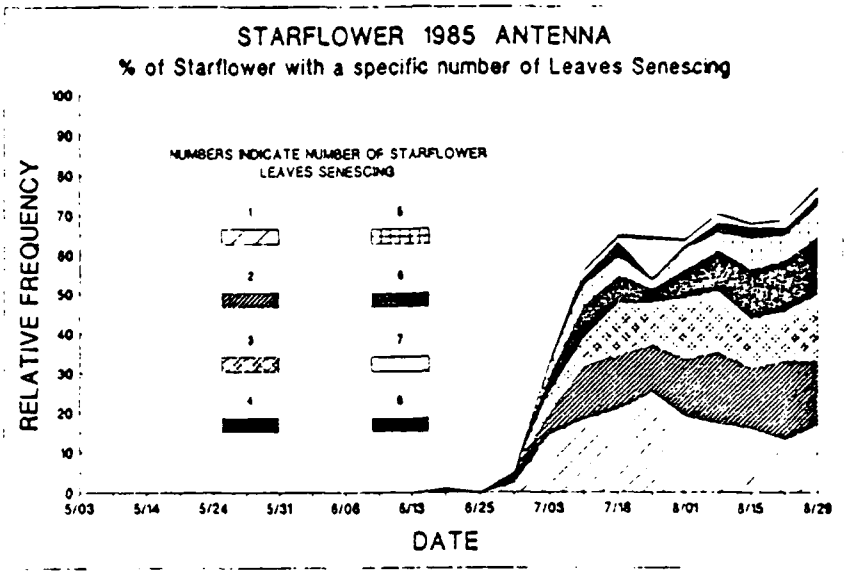
STARFLOWER 1985 ANTENNA
% of Starflower with a specific number of Leaves Senescing
NUMBERS INDICATE NUMBER OF STARFLOWER LEAVES SENESCING
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
5/03
5/14
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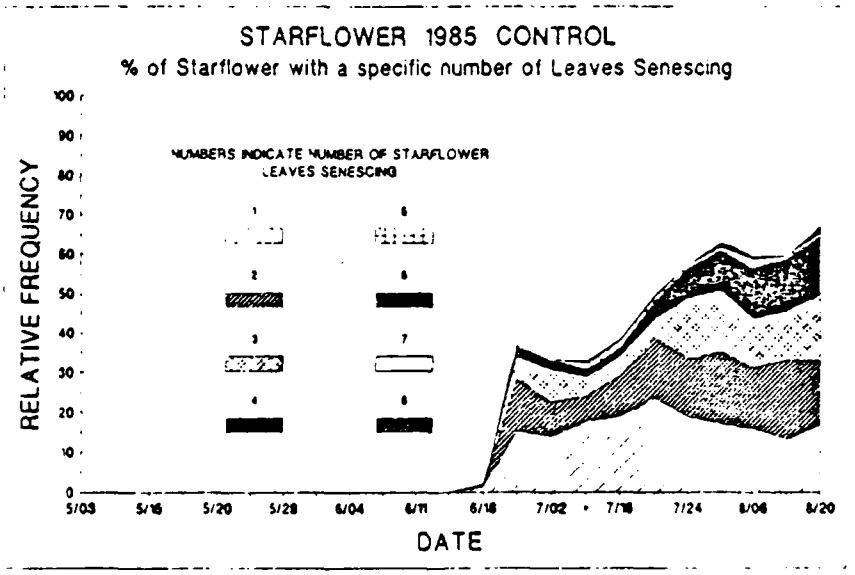
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0
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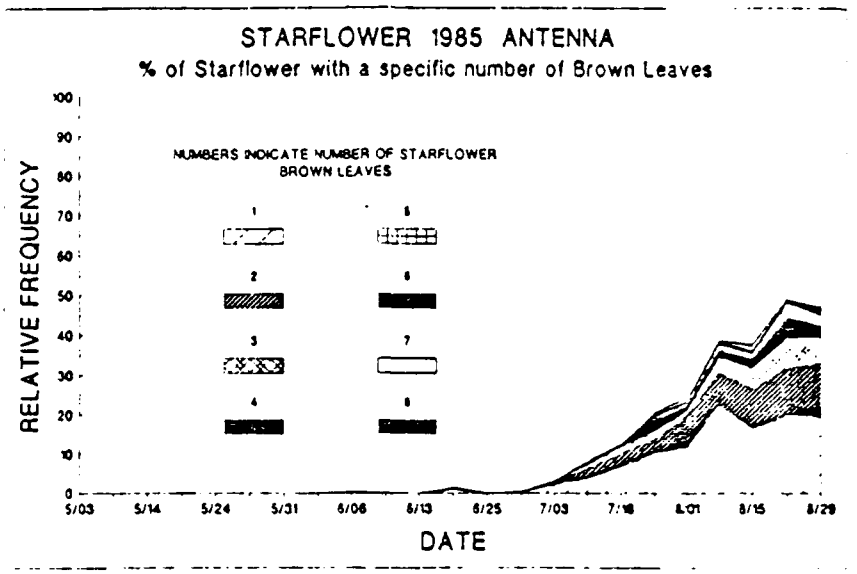
STARFLOWER 1985 ANTENNA
% of Starflower with a specific number of Brown Leaves
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RELATIVE FREQUENCY
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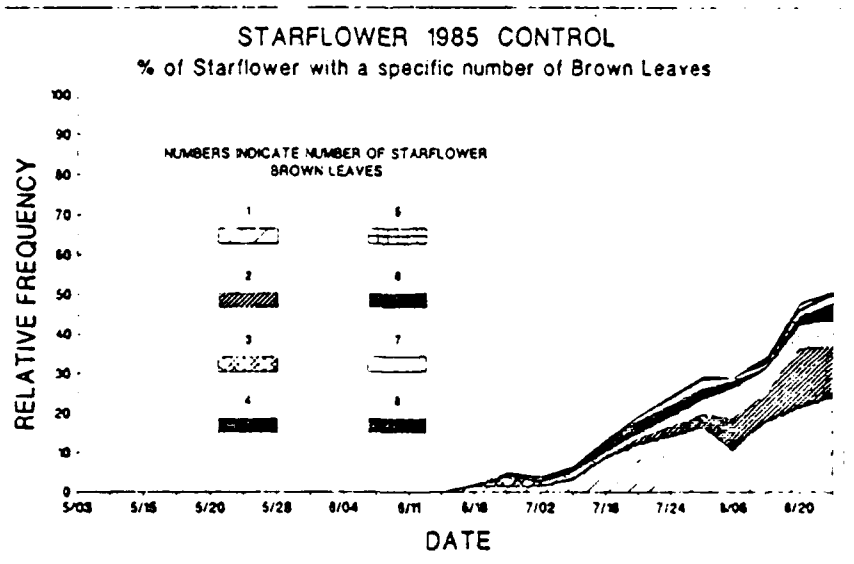
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RELATIVE FREQUENCY
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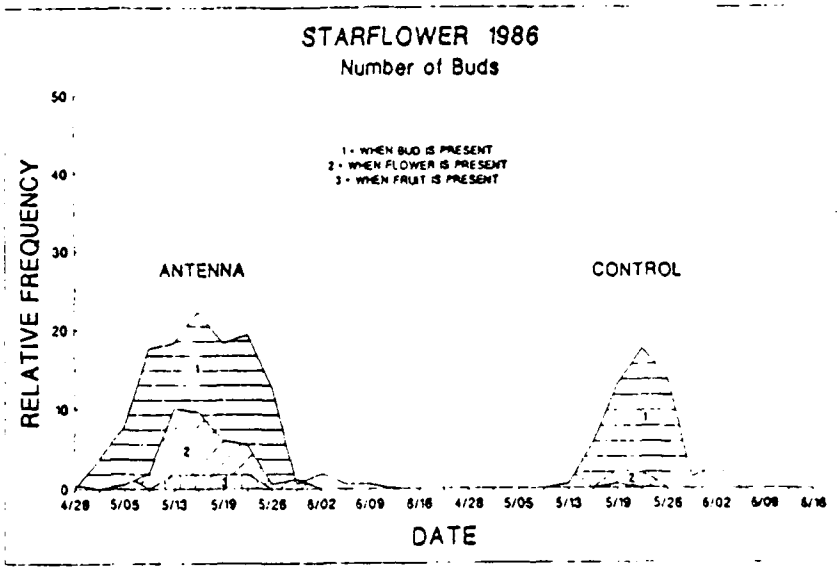
8/20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Number of Buds
1 = WHEN BUD IS PRESENT
2 = WHEN FLOWER IS PRESENT
3 = WHEN FRUIT IS PRESENT
ANTENNA
CONTROL
RELATIVE FREQUENCY
50
40
30
20
10
0
4/28 5/05 5/13 5/19 5/26 6/02 6/09 6/16 4/28 5/05 5/13 5/19 5/26 6/02 6/09 6/16
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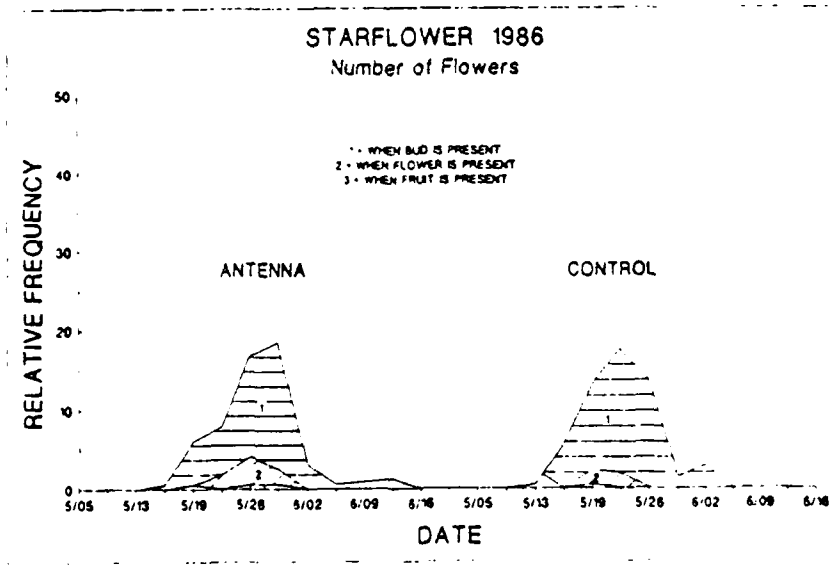
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Number of Flowers
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3 = WHEN FRUIT IS PRESENT
ANTENNA
CONTROL
RELATIVE FREQUENCY
50
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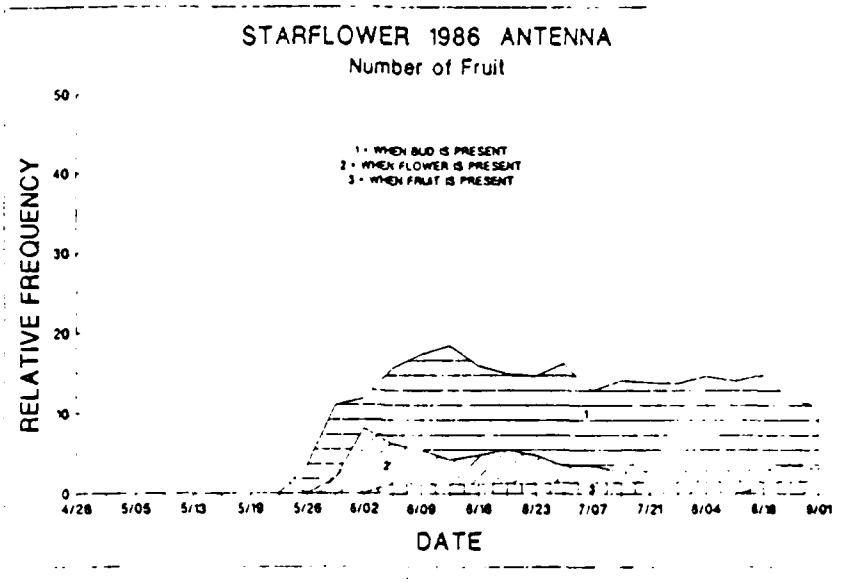
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Number of Fruit
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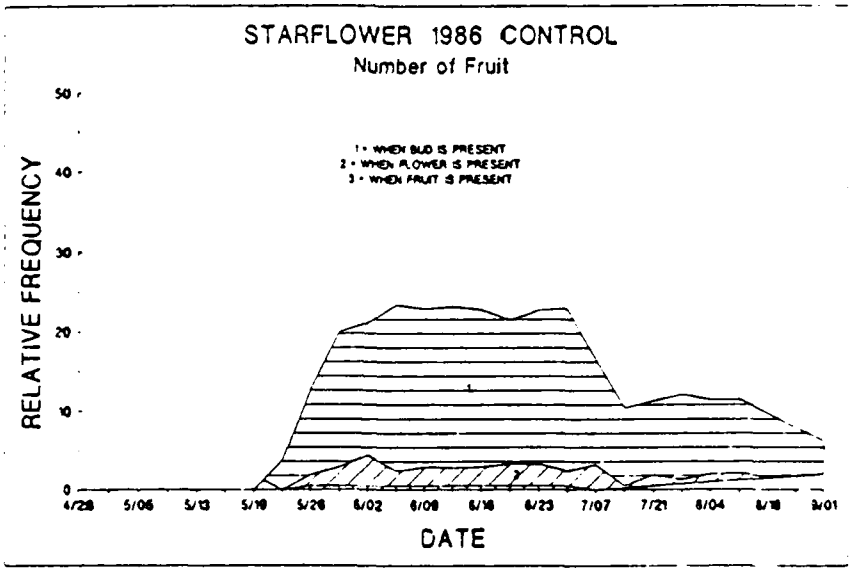
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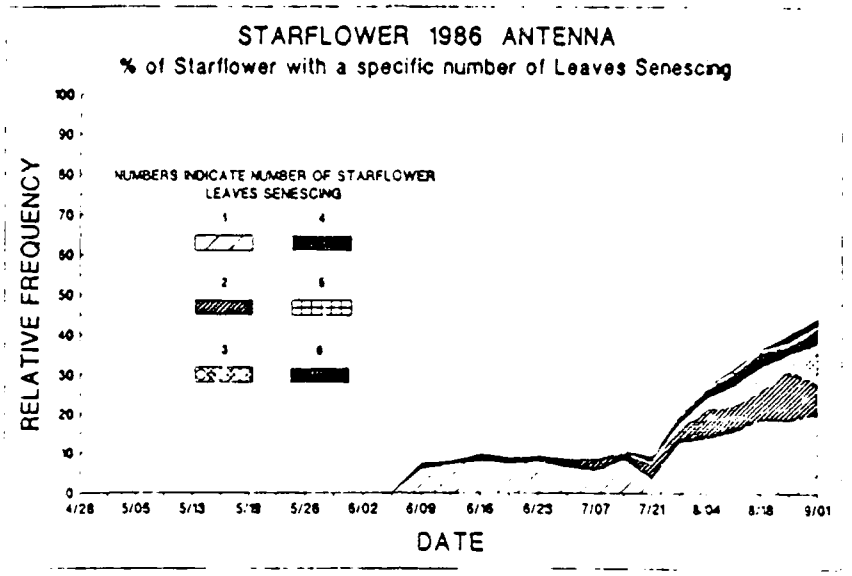
STARFLOWER 1986 ANTENNA
% of Starflower with a specific number of Leaves Senescing
RELATIVE FREQUENCY
NUMBERS INDICATE NUMBER OF STARFLOWER LEAVES SENESCING
DATE
4/28
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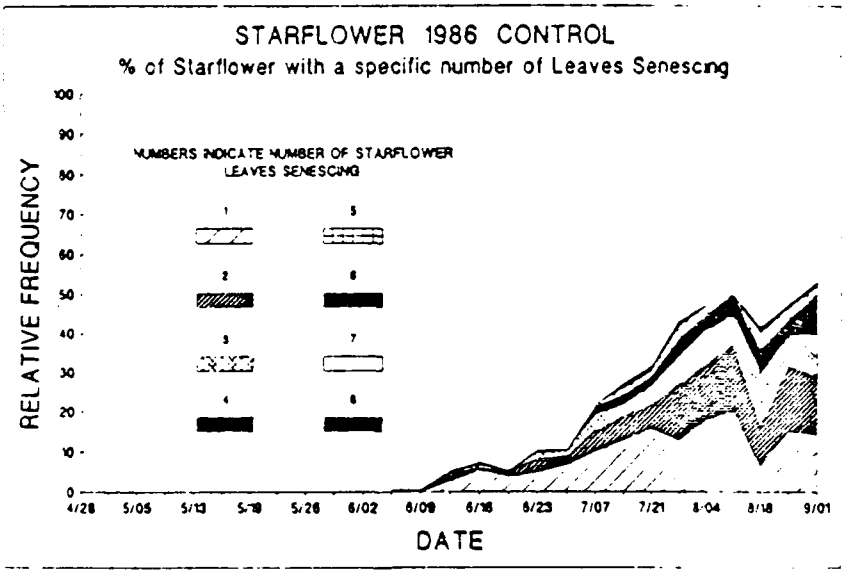
9/01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% of Starflower with a specific number of Leaves Senescing
RELATIVE FREQUENCY
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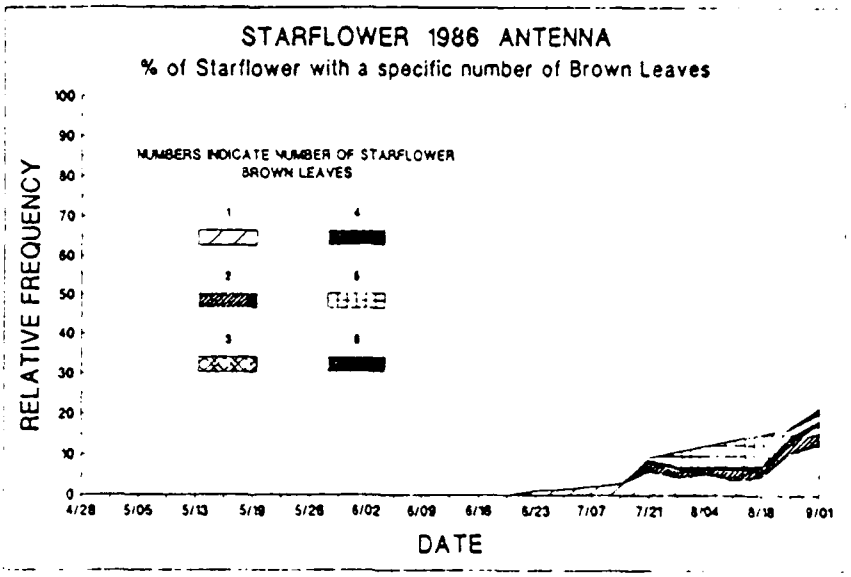
STARFLOWER 1986 ANTENNA
% of Starflower with a specific number of Brown Leaves
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RELATIVE FREQUENCY
DATE
4/28
5/05
5/13
5/19
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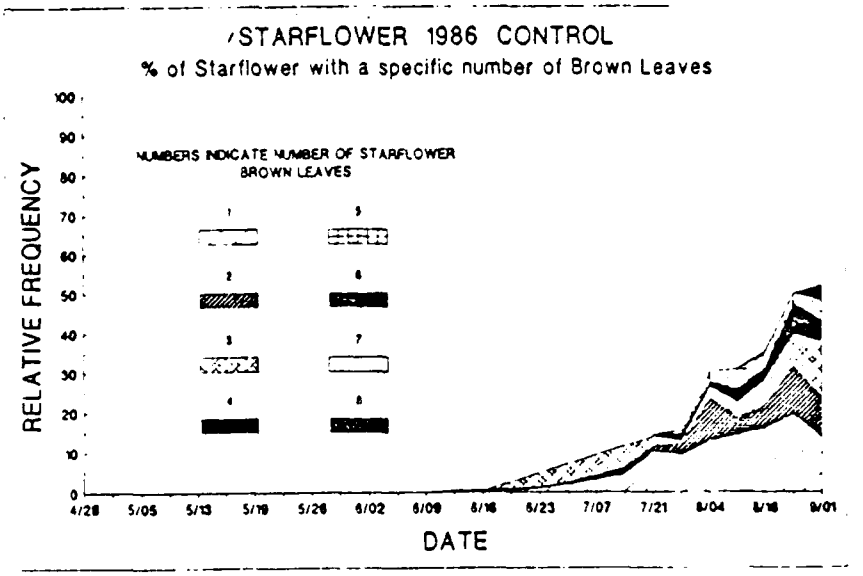
9/01


STARFLOWER 1986 CONTROL
% of Starflower with a specific number of Brown Leaves
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DATE
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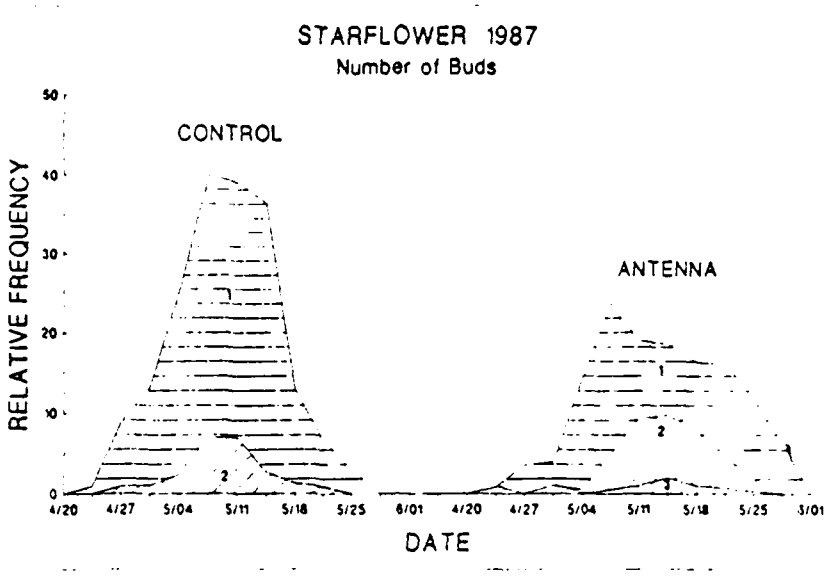
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Number of Buds
CONTROL
ANTENNA
RELATIVE FREQUENCY
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40
30
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0
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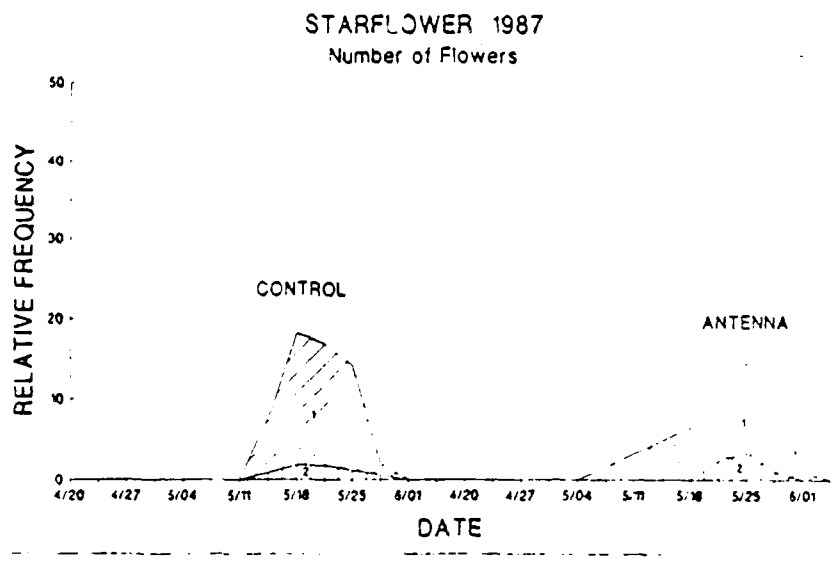
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ANTENNA
RELATIVE FREQUENCY
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40
30
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0
4/20
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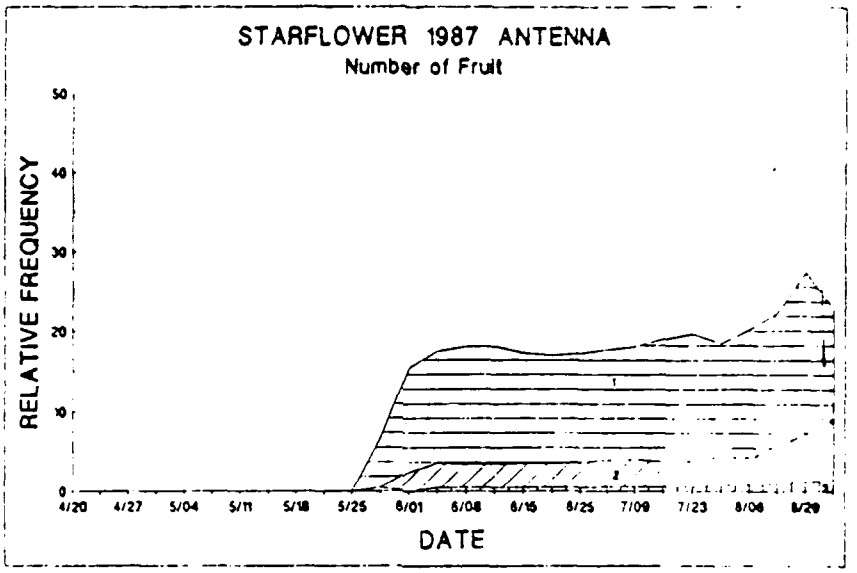
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Number of Fruit
RELATIVE FREQUENCY
0
10
20
30
40
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4/20
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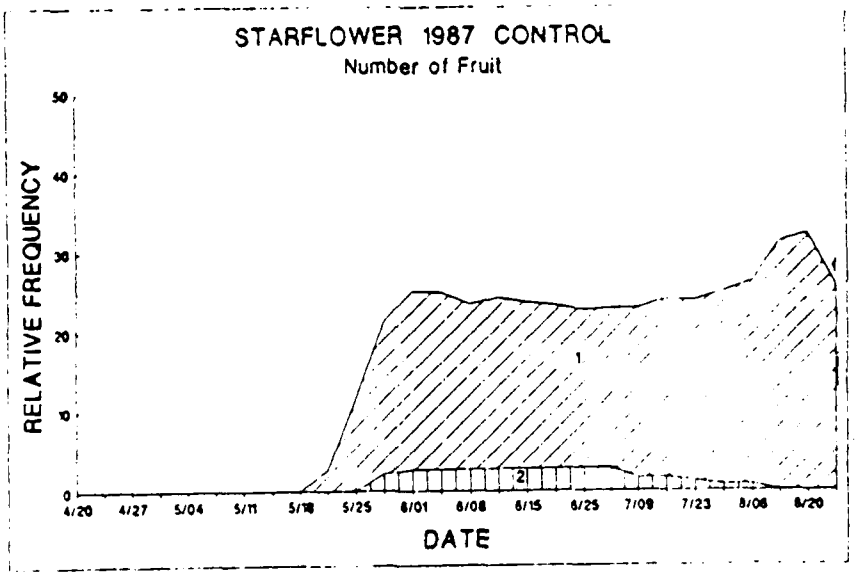
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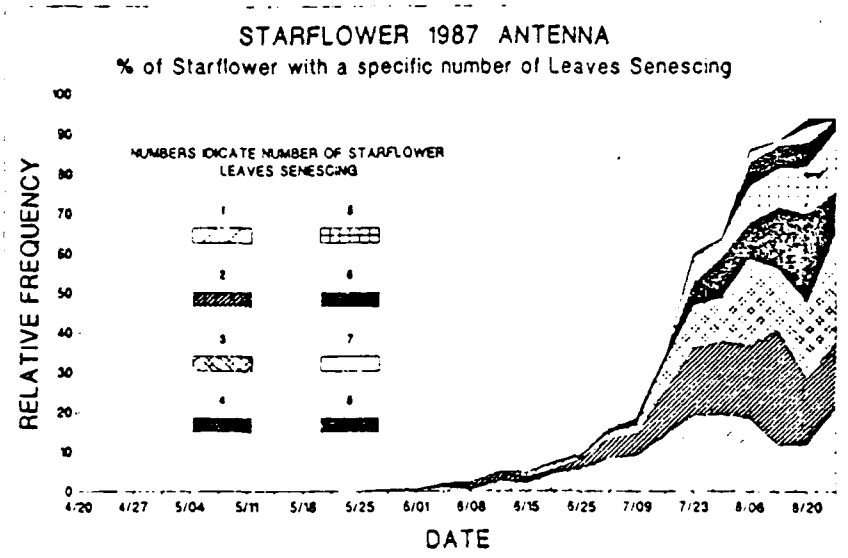
STARFLOWER 1987 ANTENNA
% of Starflower with a specific number of Leaves Senescing
NUMBERS INDICATE NUMBER OF STARFLOWER LEAVES SENESCING
RELATIVE FREQUENCY
DATE
4/20
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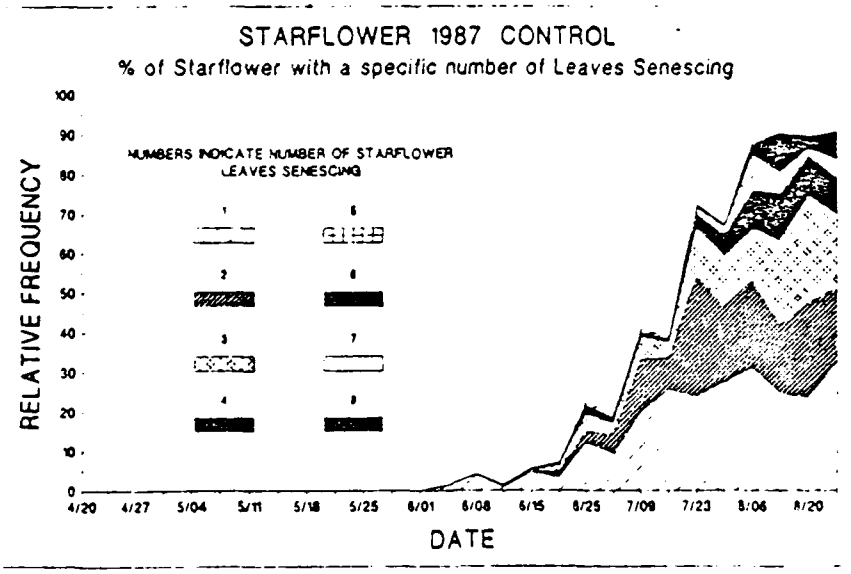
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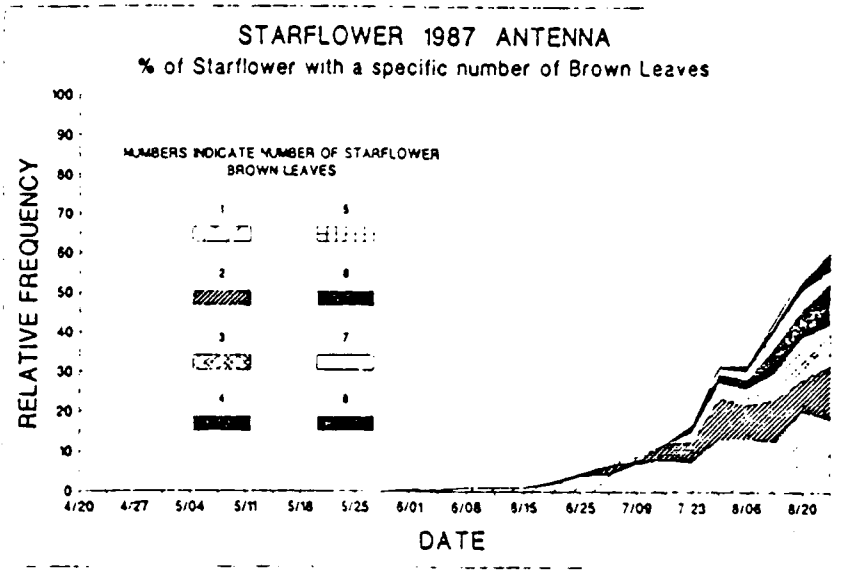
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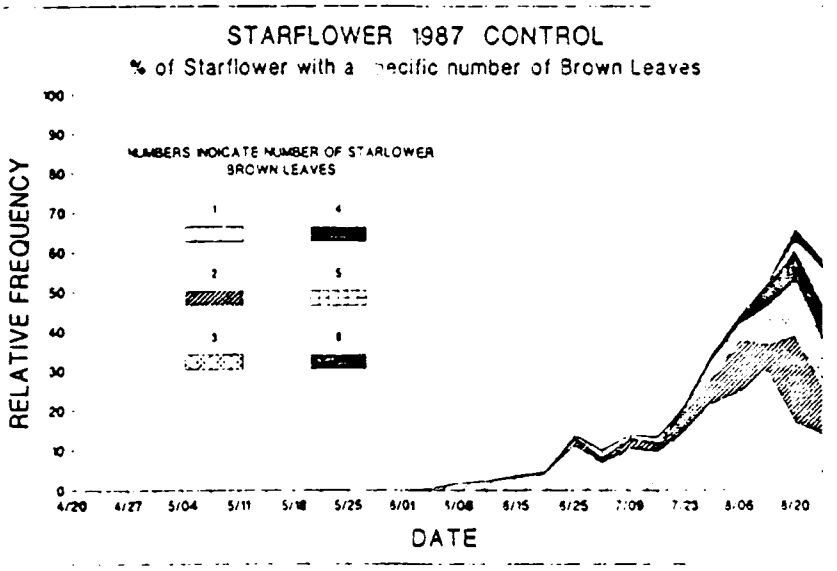
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B

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: LITTER DECOMPOSITION AND MICROFLORA
The Michigan Study Site

ANNUAL REPORT 1988

SUBCONTRACT NUMBER: EO6549-84-C-002

MICHIGAN TECHNOLOGICAL UNIVERSITY
HOUGHTON, MICHIGAN

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The Michigan Study Site

ANNUAL REPORT 1988

SUBCONTRACT NUMBER: EO6549-84-C-002

PROJECT MANAGER: Johann N. Bruhn

Research Scientist

INVESTIGATORS: Johann N. Bruhn

Susan T. Bagley

James B. Pickens

RELEASING AUTHORITY: _____

William G. Lucier
Secretary
Board of Control

MICHIGAN TECHNOLOGICAL UNIVERSITY

HOUGHTON, MICHIGAN

ABSTRACT

Four full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed on all three study units. The experimental sample units consist of 1) bagged bulk foliage samples of each litter species, for determination of both dry matter mass loss and nutrient flux, and 2) bagged individual fascicle/leaf samples, for more precise characterization of dry matter mass loss.

Precision in the raw data sets has generally been highest in the hardwood stand subunits. Among the three study species, pine has provided the most precise data, while maple data are least precise. Dry matter mass loss data are more precise than nutrient data. Our experimental design is clearly powerful enough to identify very subtle differences in the rates and patterns of bulk and individual fascicle/leaf decomposition, especially in the hardwood stand subunits.

Covariates have proven to be very useful for explaining differences in dry matter mass loss detected by ANOVA among hardwood stands, plantations, and years. Useful covariates include precipitation event frequency, air and soil temperature degree days, initial nutrient content of litter samples, initial leaf density, and variables reflecting stand species composition. Our approach to studying the nutritional aspects of litter decomposition has shifted toward use of percent nutrient contents as covariates to help explain dry matter mass loss. This work is just beginning.

Data sets have also been fitted to the simple exponential decay model. Arguments are presented, in light of our objectives, in favor of following a linear modeling approach using covariates.

Emphasis in the Red Pine Rhizosphere Streptomycete work element during 1988 was focused on the enumeration and characterization of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings in the three plantations. Counts of streptomycete levels as well as numbers of morphotypes were made. Representatives of each morphotype were further characterized, in particular for ability to degrade complex organic compounds.

Detectable differences for the 3-year data set using ANOVA were about 1% for streptomycete levels and 5% for morphotype numbers. Significant differences were found among years and months, but not between plantations. For levels, the 1987 and 1988 values were significantly higher than those for 1985 and 1986; the October values were significantly lower than for all other months. Morphotype numbers declined annually from 1985 through 1987, but levelled off in 1988. Only May and June morphotype numbers were greater than those in October. Similar, relatively stable streptomycete populations appear to have become established at all three study plantations.

Preliminary ANACOV for streptomycete levels, using air

temperature degree days and precipitation frequencies and totals as covariates, completely explained the differences between years obtained with ANOVA. A similar ANACOV for morphotype numbers, substituting soil temperature for air temperature, also explained several yearly differences. Monthly differences were nearly all explained.

In 1988, as in all previous years, the streptomycete morphotypes B and F were commonly isolated at all three plantations on all sampling dates. Other morphotypes frequently detected during 1988 were also routinely detected during previous years. Over half of the streptomycete strains detected to date were able to degrade calcium oxalate, cellulose, and lignocellulose.

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SUMMARY

Litter Decomposition and Nutrient Flux

Four full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed on all three study units (including 2 hardwood stand and 3 plantation subunits). An additional year of useful data for red pine was collected in 1983-84 at the antenna hardwood stand subunit, and the samples for the fifth complete study have been installed in the field. The experimental sample units consist of 1) bagged bulk foliage samples of each litter species, for determination of both dry matter mass loss and associated nutrient flux, and 2) bagged individual fascicle/leaf samples, for more precise characterization of dry matter mass loss patterns. Dry matter mass loss data sets are complete at this time. Nutrient (N, P, K, Ca, and Mg) data sets for the 1983-84, 1984-85, and 1985-86 studies are complete. The nutrient data sets for alternate months (May, July, September, and November) are complete from the 1986-87 study, and bulk samples from the 1987-88 study are currently being ground for analysis.

The level of precision obtained in our studies with bulk and individual fascicle/leaf samples of each litter species is expressed for convenience as the minimum shift in each sample mean which would be detected ($\alpha = 0.05$). As in previous annual reports, minimum detectable differences are presented in the summary tables for raw dry matter mass loss data representing each sample type collected on each sampling date in 1988 at each field subunit. Corresponding percent nutrient contents for bulk litter samples from the 1984-85, 1985-86, and 1986-87 studies are also presented with detectable differences. In this report, minimum detectable differences are also reported for treatment means (years, monthly sampling dates, and plantation or hardwood stand subunits) associated with analyses of variance (ANOVA) and selected analyses of covariance (ANACOV), using transformed data. Dry matter mass loss data have been transformed to the arcsin square root of X (where X is the proportion of original mass remaining) to homogenize variances prior to ANOVA or ANACOV. Precision in the raw data sets has generally been highest in the hardwood stand subunits. Among the three study species, pine has provided the most precise data, while maple data are least precise. Dry matter mass loss data are more precise than nutrient data. Our estimates of detectable differences are conservative, because ANOVA and ANACOV are much more powerful than are individual sample mean comparisons.

Three-way ANOVA, for detection of differences among years, monthly sampling dates, and plantation or hardwood stand subunits, found that bulk samples of all three litter species on both types of subunit decomposed at least as fast, and generally faster, in 1985 as in any later year. In the hardwood stands, individual fascicles/leaves of all three species also decomposed at least as fast during 1985 as during any later year. The sampling method for individual fascicles/leaves has been

improved, to involve retrieval of more envelopes containing only one fascicle/leaf per species. As a result, however, in the exposed environment of the plantations, we are finding that individual oak leaves, in particular, are decomposing faster than prior to design modification. Significant monthly progress in mass loss during May through October has been the rule in both the plantation and hardwood stand subunits. A variety of significant differences were detected among the hardwood stands and plantations using ANOVA. Many of the statistically detected differences among years, sampling dates, and subunits are attributable to very low variability within the data sets, as indicated by the minimum detectable differences reported. Many of these differences do not appear to be consequential. This issue is discussed in the section of this report entitled Statistical Design. ANOVA did not detect a difference between the hardwood stands with bulk or individual oak leaves, or with bulk pine needles.

Covariates have proven to be very useful for explaining differences in dry matter mass loss detected by ANOVA among hardwood stands, plantations, and years. With ANACOV, differences between the two hardwood stands have been explained for all sample types except for individual pine fascicles, and our ANACOV analysis of individual pine fascicles has just begun. Soil temperature degree days were useful in explaining differences in bulk oak sample mass loss between the two hardwood stands, whereas the species composition of litterfall explained differences in bulk pine and maple sample mass loss. Individual oak leaf density was effective in explaining differences among both hardwood stands and plantations.

Nearly all differences among the three plantations have been explained using ANACOV. Frequency of precipitation events explained differences in bulk pine sample mass loss, whereas the number of aspen stumps and the basal area of maple stumps in the plantations explained differences in decomposition of bulk oak and maple samples, respectively.

All differences in mass loss among years for individual pine fascicles were explained by the initial nitrogen content of the annual pine litter parent collections, and the initial density of individual oak leaves explained the difference in oak leaf mass loss between 1985 and 1988. Weather variables have yet to be evaluated as potential covariates with the four-year individual fascicle/leaf data sets. Nevertheless, frequency of precipitation events appears to be emerging as the most useful form of weather variable for explaining differences in mass loss among years, for all three species, especially in the hardwood stands. Soil or air temperature also contributed to explanation of yearly differences in the plantations.

Our approach to studying the nutritional aspects of litter decomposition has shifted from the original intent to consider nutrient fluxes as independent variables, toward use of percent nutrient contents as covariates to help explain dry matter mass loss. This work is just beginning.

For this report, the data sets for each combination of sample type and species, hardwood stand or plantation, and year have been fitted to the simple exponential decay model. The fit of these models and the rationale for their use is discussed. Arguments are presented, in light of our immediate objectives, in favor of following a linear modeling approach using covariates.

Our experimental design is clearly powerful enough to identify very subtle differences in the rates and patterns of bulk and individual fascicle/leaf decomposition, especially in the hardwood stand subunits. Our efforts in 1989 are focusing on 1) collection of the second year's data on litter decomposition in the presence of operational ELF electromagnetic fields, 2) broader use of covariate analysis to explain additional differences detected by ANOVA among years, monthly sampling dates, and subunits, and 3) providing substantial interpretation of the nutrient data sets now in hand.

Rhizoplane Streptomycetes

As in previous years, the emphasis of this work element during 1988 was focused on the enumeration and characterization of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings planted in 1984 in the three plantations. Sample sizes were maintained at six per plantation on each of the six sampling dates. Pre-weighed washed mycorrhizal fine root subsamples were macerated, serially diluted, and spread-plated onto starch casein agar amended with antifungal antibiotics. After 14 days incubation, counts of streptomycete levels as well as numbers of morphotypes were made. Representatives of each morphotype were subcultured for further characterization, in particular for ability to degrade complex organic compounds. Streptomycete level and morphotype number data were transformed to $\log_{10}$ and subjected to analysis of variance (ANOVA) for detection of differences first within the 1988 sampling season data and then among all years, sampling dates, and plantations. Analysis of covariance (ANACOV) was used to explain differences detected by ANOVA among years, sampling dates and plantations.

There was no significant difference in either streptomycete levels or morphotype numbers among the control, antenna, and ground plantations during the 1988 field season. There was, however, a significant seasonal effect on both levels and morphotype numbers. Streptomycete levels in May were lower than those of July through September, but levels from May through September were significantly higher than October levels. Morphotype numbers were relatively stable, with the exception of a significant peak in September. This seasonal trend represents a departure from the general seasonal trend of significantly greater levels and numbers earlier in the sampling season than in later months, as observed from 1985 through 1987.

When comparing the four annual streptomycete levels and morphotype numbers data sets, significant differences were found among years and months but not between plantations. For levels,

the 1987 and 1988 values were significantly higher than those for 1985 and 1986; the October values were significantly lower than for all other months. Morphotype numbers declined annually from 1985 through 1987, but levelled off in 1988. Only May and June morphotype numbers were greater than those in October. Detectable differences for the $\log^{10}$-transformed 3-year data set using ANOVA were about 1% for streptomycete levels and 5% for morphotype numbers, for years, months, and plantations. Preliminary ANACOV for streptomycete levels, using air temperature degree days and precipitation frequencies and totals as covariates, completely explained the differences between years, and greatly improved the explanation of plantation differences obtained with ANOVA. A similar ANACOV for morphotype numbers, substituting soil temperature for air temperature, greatly improved the explanation of plantation differences obtained with ANOVA, and also explained several yearly differences. Monthly differences were nearly all explained.

In 1988, as in all previous years, the streptomycete morphotypes B and F were commonly isolated at all three plantations on all sampling dates. Other morphotypes frequently detected at all three plantations during the 1988 field season were also routinely detected during previous years. Over half of the streptomycetes strains tested, representing all morphotypes detected to date, were able to degrade calcium oxalate, cellulose, and lignocellulose.

Similar, relatively stable streptomycete populations appear to have become established on the red pine seedlings at all three study plantations. During 1988, this work element will focus on 1) obtaining the second year's data on streptomycete levels and morphotype numbers associated with red pine mycorrhiza morphotype 3 in the presence of operational ELF electromagnetic fields, and 2) continuing development of covariate analysis to help explain differences in streptomycete levels and morphotype numbers between years, sapling dates, and plantations.

INTRODUCTION

Forest vegetation dominates the ELF Communications System antenna area. The litter decomposition subsystem of any forest ecosystem serves to 1) pool the nutrients relinquished by primary producers, 2) transform the essential nutrients remaining in litter or trapped by it into forms available for root uptake, and 3) release these nutrients in a regulated fashion for re-use by the autotrophs. The energy provided by litter decomposition also fuels heterotrophic dinitrogen fixation and the capture of nutrients washed from the atmosphere or leached from living plants. As heterotrophic microorganisms, streptomycetes have also been implicated in the calcium and phosphorus nutrition of conifer mycorrhizae, and could influence mycorrhizosphere microbial composition through production of antibiotics, growth factors, etc. Due to the large quantities of potentially available plant nutrients found in the litter component of forest

biomass, knowledge of key decomposition processes and their rates is essential to conceptualization of ecosystem dynamics.

Organic matter decomposition is primarily accomplished by heterotrophic microorganisms whose activities are regulated by the environment. Environmental factors which disrupt decomposition processes detract from the orderly flow of nutrients to vegetation. As a new and anthropogenic environmental factor, ELF electromagnetic fields merit investigation for possible effects on the litter decomposition subsystem.

In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic fields cause fundamental changes in forest productivity and health. This research program includes two separate yet highly integrated projects, the Herbaceous Plant Cover and Tree Studies ("Trees") project and the Litter Decomposition and Microflora project. Work elements examining 1) rates of litter decomposition and associated nutrient flux and 2) mycorrhizoplane streptomycete population dynamics were initiated simultaneously with those of the "Trees" project and on the same study units. The two work elements comprising this project complement and extend the baseline studies of the "Trees" project. The information obtained will be used for comparison of pre-operational and operational status of the study variables to evaluate possible ELF electromagnetic field effects on the local forest ecosystem. After six years, and considerable refinement, we believe that the research studies representing the two work elements of this project are both biologically defensible and statistically rigorous. The overall objectives of these work elements are to determine the impacts of ELF electromagnetic fields on:

1) rates of litter decomposition and associated nutrient flux for three important local tree species (northern red oak, red maple, and red pine), and

2) populations of streptomycete species functionally associated with mycorrhizae of planted red pine seedlings.

Ultimately, the question of whether ELF electromagnetic fields impact these segments of forest communities will be answered by testing various hypotheses (Table 1) based on the results of relatively long-term studies.

Table 1. Critical null hypotheses which will be tested to fulfill objectives of the ELF environmental monitoring program Litter Decomposition and Microflora project.

I.	There is no difference in the level of foliar litter decomposition (dry matter loss) achieved, or the seasonal pattern by which it proceeds, for each study species (northern red oak, red maple, or red pine), that cannot be explained using factors unaffected by ELF antenna operation.
II.	There is no difference in the levels of foliar litter nutrient (N, P, K, Ca, Mg) flux achieved, or the seasonal patterns by which they proceed, for each study species (northern red oak, red maple, or red pine), that cannot be explained using factors unaffected by ELF antenna operation.
III.	There is no difference in the level or the seasonal pattern of mycorrhizoplane streptomycete populations on the planted red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.
IV.	There is no difference in the representation of different identifiable strains of mycorrhizosphere streptomycetes on the planted red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.

PROJECT DESIGN

Overview of Experimental Design

Emphasis has been placed from the beginning on development of a statistically rigorous experimental design capable of separating potentially subtle ELF field effects from the natural variability associated with soil, vegetational, climatic and temporal factors. Consequently, in order to most effectively test our hypotheses, we have fully integrated our studies into those of the "Trees" project, permitting us to take full advantage of both that project's basic field design and the extensive data collected by that project on the tree, stand and site factors which influence or regulate the processes and populations we are measuring (Table 2). The measurements made and the associated analyses are discussed more thoroughly in the following sections.

The experimental designs integrate direct measures with site variables, and are a common thread through the work elements of both projects due to shared components of the field design. Because of the similarity in analyses, an understanding of this experimental design is essential. However, the rationale and progress for measurements in each work element of this study are necessarily unique and will be discussed separately in the following sections.

Table 2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Litter Decomposition and Microflora project, the objective each group of measurements relates to, and the work elements which address the necessary measurements and analyses.

Hypothesis Number	Related Objective	Measurements	Work Elements
I	1	**Monthly determinations of dry matter loss, from bulk and individual leaf litter samples of oak, maple, and pine**[2]; climatic and biotic variables, soil nutrients, litter nutrients	**1,(1),(6)**[1]
II	1	**Monthly determinations of nutrient (N, P, K, Ca, Mg) mass flux, for 1 year, from bulk foliar litter samples representing oak, maple, and pine;** climatic variables, soil nutrients, dry matter loss	**1,(1),(6)**
III	2	**Monthly counts of streptomycetes associated with mycorrhizae from planted red pine seedlings;** climatic variables, soil nutrients, mycorrhiza density, seedling growth and moisture stress	**1,(2),(4)**
IV	2	**Monthly determinations of numbers of streptomycete strains associated with Type 3 mycorrhizae from planted red pine seedlings;** climatic variables, soil nutrients, mycorrhiza density, seedling growth and moisture stress	**1,(2),(4)**

[1] Numbers in parentheses refer to work elements in the Herbaceous Plant Cover and Trees project.
[2] Bold print designates the response variable; other lists are covariates.

Field Design

The electromagnetic fields associated with the ELF system will be different at the antenna and ground locations (Anonymous, 1977). As a consequence, forest vegetation at each site could be deferentially affected by both above and below ground fields. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at a ground terminal, and at a control location some distance from the antenna.

The most general experimental design for the "Trees" project is a split-plot in space and time. Each unit (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two stand types (subunits). Pole-sized hardwood stands and red pine (Pinus resinosa Ait.) plantations comprise the treatments for this level of the design (Herbaceous Plant Cover and Tree Studies, Annual Report 1986, Figure 1, page 5). Both stand type subunits at each field unit are divided into three contiguous plots to control variation. The time factor is the number of years in which the experiment is conducted for pre-operational and operational comparisons, or the number of sampling periods in one season for year to year comparisons. It is necessary to account for time since successive measurements are made on the same whole units over a long period of time without rerandomization. A combined analysis involving a split-plot in space and time is made to determine both the average treatment response (site difference) over all years, and the consistency of such responses from year to year (Steel and Torrie 1980).

Each unit follows this design with one exception. There is no pole-sized hardwood stand subunit at the ground unit because the necessary buffer strips would have resulted in the hardwood subunit being too distant from the grounded antenna for meaningful exposure. Thus one treatment factor (hardwood stands) is eliminated at the ground unit. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. In those cases where measurements are made on only one stand type, the stand type treatment factor is irrelevant and falls out of the analysis. All other factors remain unchanged.

Statistical Design

Analysis of variance (ANOVA) and analysis of covariance (ANACOV) are used in our studies to determine effects of treatments (year, subunit, monthly sampling date, and Elf field exposure) on decomposition progress and streptomycete population levels. The statistical design employed in both study elements reported here is a factorial design with blocking and covariates. The factors included in the design vary somewhat by experiment, but include year, month, unit, and blocking. Recall that unit represents the three ELF treatments, control, ground, and antenna. Separate analyses are conducted for the hardwood stand and pine plantation subunits to satisfy the assumptions required by the analysis of variance and analysis of covariance models.

These experiments are not split-plot experiments across time, a design frequently used in the "Trees" project, because the experimental units are destructively sampled to obtain the required measurements.

Blocking is employed to control variability in all experiments, but the definition of blocks varies between experiments. The unit of blocking in the streptomycete experiments is the plantation subunit, with 6 replicates per block. The unit of blocking for the bulk leaf litter experiments is the plot (3 plots per subunit), with 2 replicates per block. For the individual leaf samples, the location of each group of leaf bags (24 groups per subunit) is a block, from which one replicate bag is removed each month. The blocking employed produces a balanced incomplete block design. This design is dictated by the spatial separation of the ELF treatments.

Our experimental design directly controls experimental error to increase precision. Indirect or statistical control can also reduce variability and remove potential sources of bias through the use of covariate analysis. This involves the use of variables (covariates) which are related to the variable of interest (variate). Covariate analysis removes the effects of an environmental source of variation that would either inflate the experimental error or inappropriately increase the variability explained by the treatments. Identification of covariates which are both biologically meaningful and independent of treatment effects is one of the most important steps in our current analysis. Covariates will have to be shown to be unaffected (both directly and indirectly) by ELF fields before they can be legitimately used to explain (with respect to ELF fields) any differences in response variables between years or units. The independence of the ambient conditions covariates will be tested by the "Trees" project.

Covariates under examination differ among the dependent variables considered (Table 2). Most analyses use climatic variables computed from weather data, such as monthly mean air temperature, monthly mean soil temperature, monthly total precipitation and the number of precipitation events each month. Depending on the variable of interest, microsite factors will also be considered. Other factors considered are more specific to the observation; for example, other covariates in the analysis of mycorrhizoplane streptomycete populations could include seedling diameter, seedling height, current season seedling shoot length, simultaneous Type 3 mycorrhiza density, and plant moisture stress. Analyses will be conducted to determine which of these are both biologically meaningful and statistically significant without violating the necessary assumptions required for the analysis of covariance (Cochran, 1957).

The adjusted treatment means presented for each ANOVA and ANACOV model employ the arc sin square root transformation of raw data. The adjusted treatment means presented for each ANACOV model are further adjusted for the covariate(s) used, and represent the transformed data after the treatment means have been adjusted for the effect of the covariate(s). Throughout the

ANACOV discussion, differences detected between means are after the effect of the covariate(s) has been considered. Thus, for example, when it is stated that decomposition failed to progress during a given month, the interpretation should be that the covariate(s) adequately explained any change that may have occurred during that month.

As noted above, the experimental design appropriately supports statistical data analysis by three-way ANOVA and ANACOV. Nevertheless, the sample means presented in figures throughout this report are accompanied by bars indicating the bounds of 95 percent confidence intervals. These confidence intervals are provided as a means of depicting relative sample variability, and do not represent the multiple (or pairwise) comparisons associated with ANOVA or ANACOV, respectively. The error bars in the figures are based on small samples, the number of observations for each specific treatment combination. ANOVA and ANACOV are based on much larger samples, and tend to explain much more variability - partly because n is larger, but also because factors used for statistical blocking, which contribute to error when calculating the confidence intervals, are included in the ANOVA model. The error bars on the figures are therefore quite conservative when compared to ANOVA results. In other words, a significant difference may be found by ANOVA or ANACOV even if all confidence intervals overlap, if a consistent and sufficient trend exists between at least two levels of a given factor (i.e., monthly sampling dates, years, or different hardwood stand or plantation subunits). We discussed an example of ANOVAs ability to detect a systematic trend in last year's report (Annual Report 1987, page 16).

As sample size increases and/or sample variance decreases, detection of a statistically significant difference between treatments becomes increasingly likely. Yet the biological effect of the given treatments on the dependent variable remains unchanged, and is either consequential (biologically significant) or not, regardless of the statistical significance achieved. According to Mize and Schultz (1985),

"Means can be consequentially and (or) statistically different. A consequential difference is a difference that is large enough to be important. A statistical difference is a difference that is larger than expected, given the variability of the characteristic that was studied. Sometimes, consequential differences are not statistically different. Also, statistical differences are sometimes not consequential. The researcher should be primarily interested in discussing the statistical significance of consequential differences."

Our experimental design with respect to litter decomposition is powerful enough to detect some statistical differences which, because of their small size, appear to be inconsequential. We view this situation to be highly preferable to the reverse situation. Nevertheless, we expect that careful use of ANACOV will explain additional differences (e.g., between certain years) detected by ANOVA.

WORK ELEMENTS

The work elements of the Litter Decomposition and Microflora project acknowledge the two diverse study areas included within this project. Data from several work elements of the "Trees" project are used to test each hypothesis posed by this project (Table 2). The following sections present a synopsis of the rationale for study, measures, and analyses conducted in each work element of this project.

ELEMENT 1: LITTER DECOMPOSITION AND NUTRIENT FLUX

Introduction

Litter decomposition comprises a complex of processes involving a variety of organisms engaged in the degradation of a wide range of organic substrates. Loss of dry matter mass over time from freshly fallen foliar litter samples has traditionally been used as a measure of fully integrated litter decomposition (Kendrick 1959, Jensen 1974, Millar 1974, Witkamp and Ausmus 1976). Both the accuracy and precision of dry matter mass loss as a sensitive index of organic matter deterioration, however, decline with time beyond approximately one year, depending on the ecosystem. Nutrient content and flux, on the other hand, provide continuously meaningful ecological information. We are also finding that mass loss characterization on the basis of individual leaves provides additional biologically meaningful information about the decomposition process and the rates at which it naturally proceeds for different litter species, beyond that provided by study of mass loss for bulk samples. Bulk sample estimates of mass loss rates actually represent running averages of the decomposition rates (including fragmentation) operating in the individual leaves comprising the bulk sample. These average rates are nevertheless essential for conversion of nutrient concentrations determined for bulk litter samples from percent values to masses for calculation of nutrient flux. The increased sample sizes accompanying individual leaf studies also permit more accurate establishment of decomposition rates for comparison between subunits, years, and monthly sampling dates.

Microfloral population shifts have been shown to influence the rate of total litter decomposition (Mitchell and Millar 1978). Conversely, dry matter mass loss and nutrient flux are useful measures of the impact of environmental perturbations on the integrated activities of the litter biota. The methods employed in these studies integrate the activities of all but the largest soil fauna, and ELF fields represent one possible cause of environmental perturbation.

Studies of litter decomposition and associated nutrient flux extend the usefulness of litter production data collected in the course of forest vegetation studies. Knowledge of litter biomass production and nutrient content conversely provide one link between the overstory and forest floor components of the forest ecosystem.

The forest vegetation at all three study sites is classified in the Acer-Quercus-Vaccinium habitat type (Coffman et al. 1983). The two hardwood species selected for study, northern red oak (Quercus rubra) and red maple (Acer rubrum), are common to both of the hardwood stand subunits. The conifer species selected for study (Pinus resinosa) exists as scattered mature specimens throughout the area. These three study species represent a range of decomposition strategies and rates. Red pine was also selected because the influence of fragmentation can be eliminated through experiments with individual fascicles.

Since the 1986 Annual Report was written, a fourth year's experience with red pine, northern red oak, and red maple foliar litter decomposition and nutrient flux has been gained on the antenna, ground, and control units. The 1987-88 study represented the fifth year of experience with red pine on the antenna and ground units. Experience to date supports the contention that mass loss and nutrient flux over time from freshly fallen foliar litter can be characterized with sufficient precision to detect subtle environmental perturbations.

Methods

Litter decomposition is being quantified as percent change over time in dry matter and nutrient (N, P, K, Ca, and Mg) masses. Analysis of litter nutrient content is being conducted by the Soils Analysis Laboratory, School of Forestry and Wood Products, Michigan Technological University. Laboratory protocol includes analysis of NBS standard . 1575 (pine needles), as every 20th sample for N and P, and s every 15th sample for cations. Experiments are conducted annually and focus on the first year following each year's autumn litterfall.

A single parent litter collection, from a single location, is made for each study species in order to avoid the effects of possible differences in substrate quality associated with geographically different litter sources. Also, differences in substrate quality among parent litter collections made in different years or at different collection sites, which might develop as a result of making separate parent litter collections at each of the ELF study sites due to different levels of exposure to ELF (76 Hz) electromagnetic fields at those study/collection sites, are avoided. Accommodation of the potential for either type of effect would complicate the experimental design and greatly increase the number of samples required in order to maintain the power of statistical tests. We feel that the additional expense attached to expanding the experimental design to include separate litter collections from each ELF study site is not warranted at this time. Should changes in northern red oak foliar nutrient concentrations be identified and attributed to ELF EM fields (Herbaceous Plant Cover and Tree Studies, Annual Report 1986, Element 7. Litter Production, pages 166-173), we will reconsider our experimental design to evaluate the effect of site specific differences in foliar litter quality on litter decomposition.

The 60 Hz (non-ELF) electromagnetic field intensities at the sites of our annual parent litter collections were measured for the first time late in 1987. It was brought to our attention early in 1988 that these fields, at the pine and maple collection sites, are higher than desired or anticipated. We contacted Mr. James Schultz of Upper Peninsula Power Co., in Houghton, MI, to obtain a professional opinion of the projected level of service to be supplied to the area around and beyond the collection sites. It is now our understanding that the power supply to the remote area involved will be constant in the foreseeable future.

As a result, we do not anticipate that differences among years in 60 Hz electromagnetic field exposure at any of our parent litter collection sites will affect substrate quality for our annual experiments. In any case, 1) we are already investigating initial substrate nutrient contents for use as covariates to explain differences among years, 2) weather-related covariates are explaining important differences among years, and 3) substrate differences among years can not affect direct site comparisons within years. In our judgement, the situation does not warrant changing the pine or maple collection sites. We believe that changing collection sites would be much more likely to jeopardize our ability to make comparisons of pre-operational vs. ELF-operational years.

Ratios of fresh to dry matter mass and initial nutrient content are determined for approximately 15 random samples taken at regular intervals during field sample preparation from each of the annual pine, oak, and maple litter parent collections. All mass loss data (dry matter as well as nutrient masses) are based on 30°C dry masses. Pre-weighed field samples are enclosed in nylon mesh envelopes (3 mm openings), disbursed in the field during early December, and retrieved monthly from early May to early December. All envelopes are constructed to lay flat on the ground. Snow cover at the study sites dictates early May to be the earliest possible recovery date, because samples are frozen to the ground until snowmelt is complete. Likewise, snow cover dictates early November as the latest possible recovery date from the plantation subunits, because samples are frozen to the ground by the early December sampling date. Early December collections are possible in the hardwood stand subunits, where sample envelopes are less severely weathered by early December, and are still relatively easy to separate from the surrounding litter.

Raw data are expressed as the proportion (X) of original dry matter or nutrient mass remaining over time. Dry matter mass loss is being studied by an individual fascicle/leaf method as well as via bulk litter samples, while nutrient flux is determined solely for the bulk litter samples. Individual fascicles/ leaves offer the opportunity to study decomposition of basic foliage units. Each individual fascicle or leaf is completely intact at the time of disbursal. The influence of fragmentation on individual pine fascicle decomposition is especially easy to eliminate by discarding any fascicles broken during the course of study.

Sufficient samples were recovered each month to permit both 1) analysis of differences in dry matter and nutrient mass losses between subunits, years, and monthly sampling dates by ANOVA and ANACOV, and 2) analysis of single exponential model rate constants (k) derived by fitting the year's dry matter mass loss data for each species on each subunit to an equation of the form $Y = e^{-kt}$ (Wieder and Lang 1982). In the past, we have derived single exponential models using the program BMDPAR, designed for derivative-free nonlinear regression. Rate constants were compared statistically by calculation of confidence intervals based on asymptotic standard deviations. With this report, we

bring our use of the single exponential model up to date, and suggest that this approach is 1) less appropriate, given our objectives, than linear modeling with covariates, and 2) potentially misleading when applied to our pine and oak data. The results of our exponential modeling are provided in the same format as previously (Annual Report 1985, pages 57 - 62), but the analyses presented here were conducted using PROC NONLIN of the Statistical Analysis System (SAS Institute, Inc. 1985).

Dry matter mass loss data are transformed to the arc sin square root of X, where X is the proportion remaining of original mass, to homogenize variances prior to correlation analysis, ANOVA, and ANACOV (Steel and Torrie 1980). The arc sin square root transformation is recommended for use with data expressed as decimal proportions less than 1.00, especially when proportions within a data set vary widely.

In all statistical analyses performed, acceptance or rejection of the null hypothesis is based on $\alpha = 0.05$, regardless of the statistical test employed. Differences which are significant with $p \leq 0.05$ are presented along with the attained significance level (p) of the test statistic. Multiple range comparisons among significant differences detected by ANOVA are being conducted via Tukey's Honestly Significant Difference (H.S.D., or w) procedure (Dowdy and Wearden 1983, Steel and Torrie 1980). Significant differences detected by ANACOV are being identified by the least square means pairwise comparison procedure (SAS Institute, Inc. 1985). All ANOVAs and ANACOVs presented here have been conducted on the mainframe computer at MTU, using PROC CORR or PROC GLM of the Statistical Analysis System (SAS Institute, Inc. 1985).

Sufficient decomposition and weather data are available for a substantial modeling effort. Several weather and biotic variables have been evaluated as covariates to date. Our use of ANACOV to explain differences detected by ANOVA has been introduced under Project Design (pages 10 - 16). Additional weather variables, as well as soil and vegetative cover variables, litterfall characteristics, and nutrient content of both the parent litter collections and retrieved samples will be evaluated as covariates in 1989, for the purpose of further explaining differences detected by ANOVA among years, sampling dates, and plantation or hardwood stand subunits. As a guiding principle, only variables which can be shown to be unaffected by ELF electromagnetic fields to date will be considered as potentially useful covariates, since ANOVA and ANACOV are proposed as our principle tools for detection of any ELF-induced shift(s) of litter decomposition rates.

Throughout the study, all bulk litter samples have been ground for nutrient analysis. The residual portion of every ground sample, beyond the portion required for analysis of N, P, K, Ca, and Mg contents, has been archived for future reference. As time and resources permit, the lignin and carbon contents of selected samples will be determined, for use as covariates. The residual portions of the autumn, 1988, parent litter collections have also been archived to permit establishment of a future

decomposition experiment, which will compare the decomposition of samples derived from litter collected during different years. This experiment will afford an opportunity to determine whether or not source litter quality variables could be responsible for any unexplained differences which remain among our annual experiments.

Our approach to studying the nutritional aspects of litter decomposition has shifted, from the original intent to consider nutrient fluxes as independent variables, toward use of percent nutrient contents as covariates to help explain dry matter mass loss. In light of this shift of emphasis, we plan to cautiously reduce the intensity of nutrient analysis conducted on samples retrieved from the field. We will continue to fully analyze the bulk standard samples representing the parent litter collections. We will also continue to archive all bulk samples retrieved from the field. However, we plan to conduct nutrient analysis only on samples retrieved during alternate months, representing May, July, September, and November. Further, nutrient analysis for each combination of species, month, and subunit plot will be conducted on a single composite subsample, half of which will be taken from each of the two samples representing each species collected monthly from each subunit plot. The remainder of each original sample will be preserved intact. This will reduce the number of nutrient analyses conducted by roughly 75 percent, but will still provide three estimates of nutrient content for each combination of species and subunit for four months during the field season. A Ph.D.-level graduate student will be hired with the resources made available by this shift of emphasis, whose responsibilities will be to facilitate further analysis as well as publication of data and results accumulated by this study.

1987-88 Study

Fresh-fallen red pine litter was again collected on polyethylene tarps (provided with drainage) spread in the LaCroix red pine plantation near Houghton, due to 1) its proximity to MTU, and 2) its remoteness from interfering ELF (76 Hz) electromagnetic fields. Fresh-fallen red maple litter was again collected near the Covered Drive, seven miles from Houghton, for the same reasons. Northern red oak litter was again collected near the northeast edge of the control plantation subunit plot 3.

Bulk pine sample envelopes measured 22 cm x 28 cm; each contained 10 g (air dry mass) of the parent collection. Bulk maple and oak sample envelopes measured 44 cm x 28 cm; each contained 15 g (air dry mass) of the parent collection. For the 1987-88 study, individual leaf envelopes measured 22 cm x 28 cm, and each contained one pine fascicle and one oak leaf.

Prior to the 1986-87 study, individual leaf envelopes contained multiple tethered leaves of a single species, and one envelope per month per species was recovered from each plantation or hardwood stand subunit plot. Beginning with the 1987 field season, we collected 1 envelope (containing one pine fascicle and one oak leaf) from each of 8 locations per plot each month. Two

advantages to this modified method were forseen:

1. The individual study leaves of each species are more clearly independent of one another.

2. Recovery of individual leaf envelopes from 24 locations per subunit (instead of 3) better represents site variability.

It appears that this adjustment in experimental design for the study of individual leaf decomposition may prevent comparison of individual oak leaf data collected in the plantations in different years by the two methods. Regardless, the ability to compare antenna and ground subunits with the control subunits will be enhanced by the improvement in experimental design.

It should be emphasized that the experimental design regarding bulk litter envelopes remains unaltered. Ten bulk litter envelopes of each species were placed together at two locations on each of the three plots comprising each subunit. One bulk envelope per species was retrieved each month from each of these 6 locations per subunit.

1988-89 Study

Fresh-fallen red pine, northern red oak, and red maple foliar litter were collected again in 1988 as described for the 1987-88 study. The same experimental design established for the 1984-85 through 1987-88 studies is being followed for bulk litter samples in the 1988-89 study. The same experimental design for individual fascicle/leaf study established with the 1986-87 study is being continued with the 1988-89 study, with the single exception that only pine fascicles and oak leaves are included.

Description of Progress

1987-88 Study

Tables 3 and 4 present mean dry matter mass loss summaries (raw, untransformed data) for the bulk and individual fascicle pine samples retrieved in 1988 (by sampling date and subunit), along with standard deviations and minimum detectable differences (based on 95 percent confidence intervals for sample means). Tables 5 and 6 present the corresponding data from all five study subunits for bulk and individual oak leaf samples. Corresponding data for bulk maple samples are presented in Table 7.

Table 3. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1988, for bulk red pine foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
4 May	0.90	0.02	2	0.92	0.01	1
1 June	0.89	0.01	1	0.91	0.01	1
29 June	0.88	0.01	1	0.89	0.01	1
28 July	0.86	0.02	2	0.88	0.01	1
31 August	0.81	0.02	2	0.77	0.01	1
28 September	0.79	0.03	3	0.74	0.01	2
2 November	0.73	0.02	3	0.73	0.01	2
1 December				0.70	0.01	1

Table 3. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May	0.92	0.00	1	0.94	0.01	1
1 June	0.89	0.02	3	0.92	0.01	1
29 June	0.88	0.01	1	0.92	0.01	1
28 July	0.8[illegible]	0.02	2	0.92	0.01	1
31 August	0.79	0.01	2	0.82	0.01	2
28 September	0.76	0.01	2	0.78	0.01	2
2 November	0.73	0.01	1	0.75	0.02	3
1 December				0.73	0.02	2

Table 3. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May	0.91	0.01	2
1 June	0.91	0.03	3
29 June	0.89	0.01	1
28 July	0.87	0.01	2
31 August	0.78	0.02	3
28 September	0.75	0.01	2
2 November	0.74	0.04	5
1 December			

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{0.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 4. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1988, for individual red pine fascicles disbursed in early December, 1987.

Sampling Date	Antenna Unit: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Unit: Hardwood Stand Mean	S.D.	%
4 May	0.91	0.02	1	0.92	0.01	1
1 June	0.90	0.02	1	0.91	0.02	1
29 June	0.88	0.02	1	0.92	0.02	1
28 July	0.85	0.02	1	0.89	0.02	1
31 August	0.78	0.02	1	0.81	0.03	1
28 September	0.72	0.04	2	0.75	0.03	2
2 November	0.70	0.02	2	0.71	0.04	3
1 December				0.70	0.02	2

Table 4. (cont)

Sampling Date	Control Unit: Plantation Mean	S.D.	%	Control Unit: Hardwood Stand Mean	S.D.	%
4 May	0.91	0.02	1	0.92	0.01	1
1 June	0.90	0.03	1	0.92	0.01	1
29 June	0.88	0.02	1	0.92	0.02	1
28 July	0.85	0.03	1	0.90	0.02	1
31 August	0.77	0.03	2	0.83	0.03	2
28 September	0.73	0.04	3	0.78	0.03	2
2 November	0.70	0.03	2	0.74	0.04	2
1 December				0.73	0.04	2

Table 4. (cont)

Sampling Date	Ground Unit: Plantation Mean	S.D.	%
4 May	0.90	0.02	1
1 June	0.89	0.02	1
29 June	0.88	0.02	1
28 July	0.85	0.03	1
31 August	0.78	0.03	2
28 September	0.73	0.03	2
2 November	0.68	0.03	2
1 December			

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation

c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean (n = 30, or less depending on fragmentation)

Table 5. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1988, for bulk northern red oak foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
4 May	0.91	0.01	2	0.93	0.02	2
1 June	0.90	0.01	1	0.93	0.01	1
29 June	0.87	0.01	2	0.91	0.02	3
28 July	0.84	0.02	3	0.90	0.02	3
31 August	0.76	0.04	5	0.78	0.03	3
28 September	0.74	0.03	4	0.74	0.02	3
2 November	0.67	0.04	7	0.68	0.04	6
1 December				0.69	0.03	4

Table 5. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May	0.95	0.01	1	0.95	0.01	1
1 June	0.90	0.02	2	0.94	0.01	1
29 June	0.89	0.03	4	0.94	0.02	2
28 July	0.87	0.02	2	0.92	0.02	2
31 August	0.79	0.02	3	0.84	0.02	3
28 September	0.75	0.03	4	0.77	0.03	4
2 November	0.68	0.04	6	0.73	0.03	4
1 December				0.76	0.02	3

Table 5. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May	0.92	0.02	2
1 June	0.89	0.01	2
29 June	0.88	0.03	4
28 July	0.84	0.03	3
31 August	0.77	0.03	4
28 September	0.72	0.02	4
2 November	0.66	0.08	12
1 December			

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean.

Table 6. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1988, for individual northern red oak leaves disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
4 May	0.89	0.04	2	0.91	0.02	1
1 June	0.84	0.04	2	0.90	0.03	2
29 June	0.78	0.07	4	0.87	0.06	3
28 July	0.70	0.09	6	0.86	0.04	2
31 August	0.61	0.11	7	0.77	0.05	3
28 September	0.55	0.10	7	0.71	0.06	4
2 November	0.53	0.08	7	0.66	0.09	6
1 December				0.64	0.12	8

Table 6. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May	0.91	0.04	2	0.94	0.02	1
1 June	0.84	0.04	2	0.92	0.02	1
29 June	0.78	0.06	3	0.91	0.03	1
28 July	0.73	0.08	5	0.88	0.04	2
31 August	0.62	0.10	7	0.81	0.04	2
28 September	0.54	0.09	7	0.75	0.06	3
2 November	0.52	0.11	9	0.71	0.06	3
1 December				0.72	0.05	3

Table 6. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May	0.88	0.05	2
1 June	0.84	0.04	2
29 June	0.79	0.06	3
28 July	0.72	0.06	4
31 August	0.60	0.07	5
28 September	0.60	0.09	6
2 November	0.52	0.08	7
1 December			

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,29} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 7. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1988, for bulk red maple foliar litter samples disbursed in early December, 1987.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
4 May	0.76	0.02	3	0.75	0.02	3
1 June	0.70	0.03	4	0.73	0.02	3
29 June	0.68	0.03	4	0.72	0.01	2
28 July	0.63	0.02	4	0.67	0.03	5
31 August	0.56	0.05	10	0.64	0.03	5
28 September	0.51	0.03	6	0.55	0.03	6
2 November	0.50	0.03	6	0.56	0.02	5
1 December				0.54	0.02	4

Table 7. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
4 May	0.77	0.03	4	0.80	0.02	3
1 June	0.72	0.03	4	0.76	0.02	3
29 June	0.68	0.02	3	0.75	0.03	5
28 July	0.64	0.03	6	0.71	0.03	4
31 August	0.57	0.04	9	0.66	0.04	6
28 September	0.54	0.02	4	0.64	0.03	5
2 November	0.49	0.05	10	0.62	0.05	9
1 December				0.60	0.02	3

Table 7. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
4 May	0.77	0.02	3
1 June	0.70	0.03	4
29 June	0.68	0.02	4
28 July	0.63	0.03	4
31 August	0.56	0.03	5
28 September	0.51	0.03	5
2 November	0.50	0.03	6
1 December			

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Overall, the data show that the following shifts in bulk and individual fascicle/leaf sample means should be detectable ($\alpha = 0.05$).

A. Pine
   1. Plantation Subunits
      a. Individual Fascicles - 3% (2% or less for 20 of the 21 means estimated)
      b. Bulk Samples - 5% (3% or less for 20 of the 21 means estimated)
   2. Hardwood Stand Subunits
      a. Individual Fascicles - 3% (2% or less for 15 of the 16 means estimated)
      b. Bulk Samples - 3% (2% or less for 15 of the 16 means estimated)

B. Oak
   1. Plantation Subunits
      a. Individual Fascicles - 9% (7% or less for 20 of the 21 means estimated)
      b. Bulk Samples - 12% (7% or less for 20 of the 21 means estimated)
   2. Hardwood Stand Subunits
      a. Individual Fascicles - 8% (6% or less for 15 of the 16 means estimated)
      b. Bulk Samples - 6% (4% or less for 15 of the 16 means estimated)

C. Maple
   1. Plantation Subunits
      a. Bulk Samples - 10% (6% or less for 18 of the 21 means estimated)
   2. Hardwood Stand Subunits
      a. Bulk Samples - 9% (6% or less for 15 of the 16 means estimated)

Exponential Decay Regressions

Nonlinear exponential decay models are often used to model litter decomposition. The functional form of the model is:

$$r = e^{-kt},$$

where r is the proportion of initial mass remaining, t is elapsed time, and k is the decay constant. Thus, the value of k can be used to compare decomposition rates for different substrates, locations, and time periods. Implicit in this functional representation is a decay process for which periodic mass loss starts at its highest level and monotonically decreases over time.

However, this representation of the process seems to display a lack of fit for at least two of the three species studied here. Appendix A presents scatter plots used to evaluate the exponential decay model for the three species. The scatter plots occur in pairs, one pair for each species. This analysis of residuals used all bulk sample data across years and plots. The first scatter plot of each pair presents the predicted and observed values on the ordinate with time in the field on the abscissa, while the second plot presents the observed residual on the ordinate with time in the field again represented on the abscissa. The plots for maple are presented on pages 319 and 320, for oak on pages 321 and 322, and for pine on pages 323 and 324.

The residual plot for maple (page 320) shows a more or less uniform distribution of errors across time. However, the residual plots for both oak (page 322) and pine (page 324) show a highly skewed error distribution, with nearly all positive residuals in the first half of the field season, and negative residuals in the second half of the field season. This pattern is characteristic for a statistical model whose functional form is not correctly specified. Because of the lack of flexibility in the model's functional form, the estimated model does not predict the actual process well anywhere for oak and pine.

The specification problem could be resolved using an approach analogous to covariance analysis in linear models. For example, measures of site moisture or temperature could be incorporated. Unfortunately, this extension would result in k values which are not comparable to those in the literature for simple exponential regressions. Moreover, k values derived using different combinations of covariates, or derived using the same covariates in a different mathematical form, would also not be comparable. Because k, temperature measures, and moisture measures are highly related, the estimates of k will have a different interpretation than in the single variable exponential decay model, and for each exponential decay model form.

In addition, the analysis of the exponential regression using covariates is more obscure than the linear model approach, and probably no more powerful. For example, consider inclusion of a measure of precipitation (represented as p) into the model.

The simple representation of the model is:

$$r = e^{-kt},$$

where k is the only parameter to be estimated. Several alternatives could be considered as reasonable ways to incorporate p into the model. Some examples are:

$$r = e^{-k_1 t - k_2 p} = e^{-k_1 t} e^{-k_2 p},$$

or

$$r = e^{-kpt},$$

or

$$r = e^{-k_1 t} + e^{-k_2 p},$$

where k, k_1, and k_2 are parameters to be estimated. Clearly, a wide variety of functional forms can be considered when covariates are included in the inherently nonlinear exponential model. Exponential models would become extremely complex with the inclusion of categorical variables and interaction terms. Traditional covariance analysis involves a more restrictive set of options. However, the hypothesis testing procedures for linear models are well documented and available in statistical packages. This is not, in general, true of nonlinear model formulations.

Of course, these complexities do not exclude the approach from use in the broader sense of scientific investigation of phenomena. Instead, they show the tremendous flexibility and usefulness of the nonlinear representation of the process. However, for the mission-oriented objective of this research (i.e., the detection of ELF field effects on the decomposition process), the nonlinear approach when covariates are included is overly complex. Taken to an extreme, concern could be raised that the analysis might even hide an effect of the ELF exposure.

For all of the reasons presented above, we believe that estimation of k constants from simple exponential regressions should not be continued, as a part of these studies, in the future.

The results for the data currently available are presented in the following tables. This portion of the exponential analysis was conducted separately for each year, site, and subunit type (i.e., hardwood stands vs. plantations). Tables 8 to 11 present the results for red pine litter from 1988, 1987, 1986, and 1985, respectively. In the plantations, bulk sample decomposition constants ($\times 10^{-4}$) ranged from 7.58 to 9.72, while individual samples ranged from 7.11 to 9.61. In the pole stand, these values ($\times 10^{-4}$) were from 7.21 to 9.77 for bulk samples and from 7.24 to 9.58 for the individual samples.

The oak litter decomposition constants tend to be similar to, but somewhat higher than, those for pine. Tables 12 to 15 present the results for oak litter from 1988, 1987, 1986, and

1985, respectively. In the plantations, bulk sample decomposition constants (x 10^{-4}) ranged from 7.95 to 9.87, while individual sample constants (x 10^{-4}) ranged from 8.75 to 18.65. The much higher values for individual oak samples occurred in the 1986-87 and 1987-88 studies, and correspond to improved sampling procedure (Annual Report 1987, pp. 23-24). In the pole stands, these values (x 10^{-4}) were from 6.81 to 9.44 for the bulk samples, and from 7.63 to 10.24 for the individual samples.

The maple litter decomposition constants were much higher than those estimated for either pine or oak. This result is consistent with previous results (Annual Report 1985, pp. 57-62) and the literature (e.g. Wieder and Lang 1982). Tables 16 to 19 present the results for maple litter from 1988, 1987, 1986, and 1985, respectively. In the plantations, estimates of k (x 10^{-4}) ranged from 15.35 to 28.75 for the bulk samples, and from 23.14 to 29.96 for the individual samples. Individual samples of maple were suspended after the 1986 field season because of the difficulty of identifying the initial sample given the extensive decomposition of this species. In the pole stand, the decomposition constant estimates (x 10^{-4}) ranged from 10.98 to 20.34 for the bulk samples, and from 15.03 to 21.17 for the individual samples.

Table 8. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from red pine foliar litter during 1988.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	7.90	8.90	8.57	8.08
SD_k ($\times 10^{-4}$)[d]	0.22	0.20	0.30	0.20
df[e]	41	145	47	178
CI_k upper ($\times 10^{-4}$)[f]	8.36	9.29	9.17	8.48
CI_k lower ($\times 10^{-4}$)	7.45	8.51	7.97	7.69
Σ residuals^2	0.033	0.287	0.083	0.513

Table 8 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	8.09	8.88	7.21	7.24
SD_k ($\times 10^{-4}$)[d]	0.29	0.22	0.31	0.17
df[e]	41	133	47	177
CI_k upper ($\times 10^{-4}$)[f]	8.66	9.32	7.84	7.58
CI_k lower ($\times 10^{-4}$)	7.51	8.45	6.59	6.89
Σ residuals^2	0.054	0.300	0.095	0.417

Table 8 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	8.15	9.23
SD_k ($\times 10^{-4}$)[d]	0.31	0.20
df[e]	41	146
CI_k upper ($\times 10^{-4}$)[f]	8.78	9.62
CI_k lower ($\times 10^{-4}$)	7.51	8.83
Σ residuals^2	0.064	0.307

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 10 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed fascicles in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 9. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from red pine foliar litter during 1987.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	7.58	9.48	8.96	8.61
SD_k ($\times 10^{-4}$)[d]	0.36	0.33	0.30	0.17
df[e]	41	148	47	170
CI_k upper ($\times 10^{-4}$)[f]	8.30	10.12	9.56	8.94
CI_k lower ($\times 10^{-4}$)	6.86	8.84	8.36	8.27
Σ residuals^2	0.081	0.774	0.077	0.311

Table 9 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	8.75	9.61	8.85	8.41
SD_k ($\times 10^{-4}$)[d]	0.28	0.20	0.28	0.20
df[e]	41	144	47	154
CI_k upper ($\times 10^{-4}$)[f]	9.31	10.00	9.41	8.81
CI_k lower ($\times 10^{-4}$)	8.19	9.22	8.29	8.01
Σ residuals^2	0.046	0.269	0.068	0.367

Table 9 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	8.21	8.98
SD_k ($\times 10^{-4}$)[d]	0.35	0.23
df[e]	41	134
CI_k upper ($\times 10^{-4}$)[f]	8.91	9.43
CI_k lower ($\times 10^{-4}$)	7.51	8.53
Σ residuals^2	0.074	0.321

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 10 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed fascicles in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 10. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from red pine foliar litter during 1986.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	7.95	7.94	8.36	7.54
SD_k ($\times 10^{-4}$)[d]	0.30	0.18	0.31	0.16
df[e]	41	192	47	223
CI_k upper ($\times 10^{-4}$)[f]	8.56	8.30	8.98	7.85
CI_k lower ($\times 10^{-4}$)	7.34	7.59	7.74	7.23
Σ residuals^2	0.058	0.439	0.087	0.506

Table 10 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	9.05	8.13	8.43	7.70
SD_k ($\times 10^{-4}$)[d]	0.33	0.16	0.27	0.17
df[e]	41	1	47	213
CI_k upper ($\times 10^{-4}$)[f]	9.71	8.45	8.98	8.03
CI_k lower ($\times 10^{-4}$)	8.39	7.81	7.88	7.36
Σ residuals^2	0.065	0.258	0.069	0.521

Table 10 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	9.05	9.17
SD_k ($\times 10^{-4}$)[d]	0.32	0.17
df[e]	41	186
CI_k upper ($\times 10^{-4}$)[f]	9.71	9.50
CI_k lower ($\times 10^{-4}$)	8.40	8.84
Σ residuals^2	0.064	0.346

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 10 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed fascicles in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 11. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from red pine foliar litter during 1985.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	8.67	7.11	9.34	7.88
SD_k ($\times 10^{-4}$)[d]	0.27	0.18	0.23	0.12
df[e]	41	174	47	230
CI_k upper ($\times 10^{-4}$)[f]	9.21	7.46	9.80	8.12
CI_k lower ($\times 10^{-4}$)	8.13	6.76	8.88	7.65
Σ residuals^2	0.049	0.382	0.049	0.338

Table 11 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	9.16	7.83	9.77	9.58
SD_k ($\times 10^{-4}$)[d]	0.23	0.19	0.15	0.12
df[e]	41	170	45	233
CI_k upper ($\times 10^{-4}$)[f]	9.62	8.20	10.07	9.81
CI_k lower ($\times 10^{-4}$)	8.70	7.46	9.47	9.35
Σ residuals^2	0.034	0.405	0.019	0.314

Table 11 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	9.72	7.66
SD_k ($\times 10^{-4}$)[d]	0.27	0.17
df[e]	41	173
CI_k upper ($\times 10^{-4}$)[f]	10.26	8.01
CI_k lower ($\times 10^{-4}$)	9.17	7.32
Σ residuals^2	0.046	0.375

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 10 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed fascicles in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 12. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from northern red oak foliar litter during 1988.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	9.31	16.15	8.65	10.24
SD_k ($\times 10^{-4}$)[d]	0.41	0.50	0.45	0.31
df[e]	40	165	47	193
CI_k upper ($\times 10^{-4}$)[f]	10.14	17.14	9.56	10.85
CI_k lower ($\times 10^{-4}$)	8.48	15.16	7.73	9.63
Σ residuals^2	0.097	1.712	0.189	1.312

Table 12 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	8.44	15.92	6.81	8.02
SD_k ($\times 10^{-4}$)[d]	0.43	0.52	0.37	0.21
df[e]	41	164	47	190
CI_k upper ($\times 10^{-4}$)[f]	9.31	16.95	7.55	8.45
CI_k lower ($\times 10^{-4}$)	7.57	14.88	6.07	7.60
Σ residuals^2	0.119	1.859	0.138	0.049

Table 12 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	9.51	15.87
SD_k ($\times 10^{-4}$)[d]	0.48	0.44
df[e]	41	165
CI_k upper ($\times 10^{-4}$)[f]	10.48	16.74
CI_k lower ($\times 10^{-4}$)	8.55	14.99
Σ residuals^2	0.137	1.363

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 12 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed leaves in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 13. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from northern red oak foliar litter during 1987.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	9.49	18.65	7.78	9.51
SD_k ($\times 10^{-4}$)[d]	0.51	0.65	0.41	0.26
df[e]	41	172	47	190
CI_k upper ($\times 10^{-4}$)[f]	10.53	19.94	8.60	10.01
CI_k lower ($\times 10^{-4}$)	8.45	17.35	6.95	9.00
Σ residuals^2	0.153	2.775	0.156	0.898

Table 13 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	8.31	17.83	8.60	9.91
SD_k ($\times 10^{-4}$)[d]	0.44	0.58	0.43	0.28
df[e]	41	172	47	191
CI_k upper ($\times 10^{-4}$)[f]	9.19	18.98	9.46	10.46
CI_k lower ($\times 10^{-4}$)	7.43	16.68	7.74	9.37
Σ residuals^2	0.117	2.283	0.154	1.024

Table 13 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	8.48	16.65
SD_k ($\times 10^{-4}$)[d]	0.63	0.64
df[e]	40	160
CI_k upper ($\times 10^{-4}$)[f]	9.76	17.92
CI_k lower ($\times 10^{-4}$)	7.20	15.38
Σ residuals^2	0.231	2.534

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 12 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed leaves in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 14. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from northern red oak foliar litter during 1986.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	8.31	9.35	6.83	7.63
SD_k ($\times 10^{-4}$)[d]	0.47	0.39	0.45	0.24
df[e]	41	209	47	239
CI_k upper ($\times 10^{-4}$)[f]	9.26	10.11	7.74	8.10
CI_k lower ($\times 10^{-4}$)	7.36	8.58	5.93	7.17
Σ residuals^2	0.141	2.328	0.202	1.367

Table 14 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	7.95	8.75	7.09	8.46
SD_k ($\times 10^{-4}$)[d]	0.48	0.32	0.37	0.29
df[e]	41	209	47	239
CI_k upper ($\times 10^{-4}$)[f]	8.93	9.38	7.83	9.02
CI_k lower ($\times 10^{-4}$)	6.97	8.12	6.36	7.90
Σ residuals^2	0.151	1.630	0.132	1.905

Table 14 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	8.33	9.16
SD_k ($\times 10^{-4}$)[d]	0.46	0.35
df[e]	40	209
CI_k upper ($\times 10^{-4}$)[f]	9.25	9.85
CI_k lower ($\times 10^{-4}$)	7.40	8.48
Σ residuals^2	0.124	1.851

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 12 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed leaves in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 15. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from northern red oak foliar litter during 1985.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	8.82	10.63	8.17	9.16
SD_k ($\times 10^{-4}$)[d]	0.40	0.44	0.42	0.24
df[e]	41	200	47	230
CI_k upper ($\times 10^{-4}$)[f]	9.63	11.50	9.00	9.64
CI_k lower ($\times 10^{-4}$)	8.02	9.76	7.33	8.68
Σ residuals^2	0.107	2.823	0.174	1.338

Table 15 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	8.47	10.33	9.44	9.45
SD_k ($\times 10^{-4}$)[d]	0.50	0.35	0.46	0.27
df[e]	41	200	47	230
CI_k upper ($\times 10^{-4}$)[f]	9.48	11.03	10.37	9.97
CI_k lower ($\times 10^{-4}$)	7.45	9.63	8.51	8.92
Σ residuals^2	0.174	1.835	0.197	1.581

Table 15 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	9.87	11.92
SD_k ($\times 10^{-4}$)[d]	0.37	0.38
df[e]	41	200
CI_k upper ($\times 10^{-4}$)[f]	10.61	12.67
CI_k lower ($\times 10^{-4}$)	9.12	11.16
Σ residuals^2	0.087	2.001

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 12 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed leaves in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 16. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from red maple foliar litter during 1988.

	Antenna Site	
	Plantation	Pole-Stand
	Bulk[b]	Bulk
k ($\times 10^{-4}$)	21.14	17.88
SD_k ($\times 10^{-4}$)[c]	0.37	0.28
df[d]	41	47
CI_k upper ($\times 10^{-4}$)[e]	21.89	18.45
CI_k lower ($\times 10^{-4}$)	20.39	17.32
Σ residuals^2	0.047	0.044

Table 16 (cont.)

	Control Site	
	Plantation	Pole-Stand
	Bulk	Bulk
k ($\times 10^{-4}$)	20.34	15.10
SD_k ($\times 10^{-4}$)[c]	0.39	0.27
df[d]	40	47
CI_k upper ($\times 10^{-4}$)[e]	21.14	15.63
CI_k lower ($\times 10^{-4}$)	19.55	14.56
Σ residuals^2	0.052	0.046

Table 16 (cont.)

	Ground Site
	Plantation
	Bulk
k ($\times 10^{-4}$)	20.94
SD_k ($\times 10^{-4}$)[c]	0.34
df[d]	41
CI_k upper ($\times 10^{-4}$)[e]	21.63
CI_k lower ($\times 10^{-4}$)	20.25
Σ residuals^2	0.040

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 12 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ asymptotic standard deviation
d/ degrees of freedom
e/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 17. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from red maple foliar litter during 1987.

	Antenna Site	
	Plantation	Pole-Stand
	Bulk[b]	Bulk
k ($\times 10^{-4}$)	19.12	12.42
SD_k ($\times 10^{-4}$)[c]	0.61	0.42
df[d]	41	47
CI_k upper ($\times 10^{-4}$)[e]	20.35	13.26
CI_k lower ($\times 10^{-4}$)	17.89	11.58
Σ residuals^2	0.134	0.126

Table 17 (cont.)

	Control Site	
	Plantation	Pole-Stand
	Bulk	Bulk
k ($\times 10^{-4}$)	15.35	10.98
SD_k ($\times 10^{-4}$)[c]	0.35	0.25
df[d]	41	47
CI_k upper ($\times 10^{-4}$)[e]	16.06	11.47
CI_k lower ($\times 10^{-4}$)	14.63	10.48
Σ residuals^2	0.055	0.047

Table 17 (cont.)

	Ground Site
	Plantation
	Bulk
k ($\times 10^{-4}$)	16.55
SD_k ($\times 10^{-4}$)[c]	0.62
df[d]	41
CI_k upper ($\times 10^{-4}$)[e]	17.81
CI_k lower ($\times 10^{-4}$)	15.29
Σ residuals^2	0.159

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 12 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ asymptotic standard deviation
d/ degrees of freedom
e/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 18. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from red maple foliar litter during 1986.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	18.16	28.97	11.78	15.73
SD_k ($\times 10^{-4}$)[d]	0.68	1.40	0.32	0.73
df[e]	40	74	47	91
CI_k upper ($\times 10^{-4}$)[f]	19.53	31.76	12.43	17.18
CI_k lower ($\times 10^{-4}$)	16.79	26.19	11.13	14.28
Σ residuals^2	0.168	1.401	0.079	1.138

Table 18 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	15.75	25.15	12.07	15.03
SD_k ($\times 10^{-4}$)[d]	0.59	1.14	0.26	0.49
df[e]	40	75	47	95
CI_k upper ($\times 10^{-4}$)[f]	16.94	27.42	12.59	16.01
CI_k lower ($\times 10^{-4}$)	14.55	22.88	11.54	14.06
Σ residuals^2	0.143	1.142	0.052	0.620

Table 18 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	18.11	27.79
SD_k ($\times 10^{-4}$)[d]	0.74	1.53
df[e]	39	61
CI_k upper ($\times 10^{-4}$)[f]	19.61	30.86
CI_k lower ($\times 10^{-4}$)	16.61	24.72
Σ residuals^2	0.188	1.157

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 12 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed leaves in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

Table 19. Characteristics of single exponential models[a] fitted to first year dry matter mass loss from red maple foliar litter during 1985.

	Antenna Site			
	Plantation		Pole-Stand	
	Bulk[b]	Individual[c]	Bulk	Individual
k ($\times 10^{-4}$)	24.41	26.06	19.29	18.71
SD_k ($\times 10^{-4}$)[d]	0.60	0.71	0.44	0.35
df[e]	41	207	47	233
CI_k upper ($\times 10^{-4}$)[f]	25.62	27.46	20.16	19.40
CI_k lower ($\times 10^{-4}$)	23.20	24.66	18.41	18.03
Σ residuals^2	0.107	3.443	0.102	1.630

Table 19 (cont.)

	Control Site			
	Plantation		Pole-Stand	
	Bulk	Individual	Bulk	Individual
k ($\times 10^{-4}$)	23.68	23.14	20.34	21.17
SD_k ($\times 10^{-4}$)[d]	0.65	0.65	0.28	0.47
df[e]	41	209	46	239
CI_k upper ($\times 10^{-4}$)[f]	25.00	24.41	20.91	22.11
CI_k lower ($\times 10^{-4}$)	22.37	21.86	19.77	20.24
Σ residuals^2	0.131	3.401	0.039	2.766

Table 19 (cont.)

	Ground Site	
	Plantation	
	Bulk	Individual
k ($\times 10^{-4}$)	28.75	29.96
SD_k ($\times 10^{-4}$)[d]	0.69	0.82
df[e]	41	208
CI_k upper ($\times 10^{-4}$)[f]	30.16	31.59
CI_k lower ($\times 10^{-4}$)	27.35	28.34
Σ residuals^2	0.115	3.819

a/ Models ($Y = e^{-kt}$) were derived using the SAS procedure NONLIN. Y is the proportion of dry matter mass remaining; t is the elapsed time in days since disbursal; k is the rate constant.
b/ 12 g of foliage in 3 mm mesh nylon envelopes (12 in x 8 in)
c/ individual pre-weighed leaves in 3 mm mesh nylon envelopes
d/ asymptotic standard deviation
e/ degrees of freedom
f/ upper and lower bounds of confidence interval ($\alpha = 0.05$)

ANOVA Results - Individual Fascicle/Leaf Samples

Individual Pine Fascicles

Table 20 presents the 3-way ANOVA table for detection of significant differences in dry matter mass loss among years, monthly sampling dates, and plantations; Table 22 presents the corresponding ANOVA table for the hardwood stands. Tables 21 and 23 present 1) means and standard errors for the treatments (years, months, subunits), 2) detectable differences for each treatment based on 95 percent confidence intervals, and 3) significant differences detected by ANOVA and identified by Tukey's H.S.D. procedure (SAS Institute Inc. 1985). Table 21 corresponds to the plantation ANOVA, and Table 23 corresponds to the hardwood stand ANOVA. Monthly samples were collected near the beginning of the months indicated for multiple comparisons.

Individual pine fascicles placed in the ground or control plantation decomposed faster than those placed in the antenna plantation. The individual pine fascicles placed in the control hardwood stand decomposed faster than those placed in the antenna hardwood stand. Comparing years in the plantations, 1987 and 1988 samples decomposed fastest and 1985 samples slowest; in the hardwood stands, 1985 samples decomposed fastest and 1986 and 1988 samples slowest. Significant monthly progress occurred in the plantations, while progress in the hardwood stands occurred from June through October. Detectable differences were extremely low, well below 1 percent of the yearly, monthly and subunit mean values. This accounts for the significance of some of the differences between very close mean values.

Figures 1 and 2 present comparisons of monthly progress in dry matter mass loss during the 1987-88 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Corresponding data for the 1986-87, 1985-86, and 1984-85 studies, respectively, were presented as Figures 1-3 in Annual Report 1987. The similarity among plantation and hardwood stand subunits is encouraging, and suggests that ANACOV may explain the differences detected by ANOVA. Some of the differences detected between subunits by ANOVA would be difficult to anticipate from these figures. This is a result of the great power of ANOVA procedures, which is due largely to the pooled variance estimates employed. Thus, the single sample error limits depicted in the figures are much more conservative than is ANOVA.

Figure 3 presents comparisons of monthly progress in dry matter mass loss during the 1984-85, 1985-86, 1986-87, and 1987-88 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 4 through 7 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. While the significant differences detected by ANOVA are apparent, the differences between annual studies are not particularly

Table 20. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual pine** needles in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	19.72		758.76	0.0000	0.81
Year	3		0.27	38.12	0.0001	
Month	6		19.28	1360.35	0.0000	
Plantation	2		0.05	11.14	0.0001	
Error	1910	4.51				
Corrected Total	1921	24.23				

Table 21. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 20.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	7
1985	1.17	0.002	0.34	1985						
1986	1.15	0.002	0.34	1986				*		
1987	1.14	0.002	0.34	1987				*	*	
1988	1.14	0.002	0.34	1988				*	*	
Month					1	2	3	4	5	6
May	1.29	0.003	0.46	May						
June	1.26	0.003	0.47	June	*					
July	1.21	0.003	0.49	July	*	*				
August	1.16	0.003	0.51	Aug	*	*	*			
September	1.09	0.003	0.54	Sept	*	*	*	*		
October	1.04	0.003	0.57	Oct	*	*	*	*	*	
November	1.01	0.003	0.58	Nov	*	*	*	*	*	*
Plantation								G		A
Ground	1.15	0.002	0.34	Ground						
Antenna	1.16	0.002	0.34	Antenna				*		
Control	1.15	0.002	0.34	Control						*

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

Table 22. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual pine** needles in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	16.89		725.18	0.0000	0.84
Year	3		0.68	107.69	0.0001	
Month	7		15.93	1075.08	0.0000	
Hardwood Stand	1		0.04	19.50	0.0001	
Error	1563	3.31				
Corrected Total	1574	20.20				

Table 23. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 22.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5		6	7
1985	1.12	0.002	0.35	1985				*			
1986	1.17	0.002	0.34	1986				*		*	
1987	1.15	0.003	0.51	1987				*			*
1988	1.17	0.002	0.34	1988							
Month					1	2	3	4	5	6	7
May	1.28	0.003	0.46	May							
June	1.27	0.003	0.46	June							
July	1.24	0.003	0.47	July	*	*					
August	1.20	0.003	0.49	Aug	*	*	*				
September	1.11	0.003	0.53	Sept	*	*	*	*			
October	1.06	0.003	0.55	Oct	*	*	*	*	*		
November	1.02	0.003	0.58	Nov	*	*	*	*	*	*	
December	1.03	0.004	0.76	Dec	*	*	*	*	*	*	
Hardwood Stand								A			
Antenna	1.15	0.002	0.34	Antenna							
Control	1.14	0.002	0.34	Control				*			

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

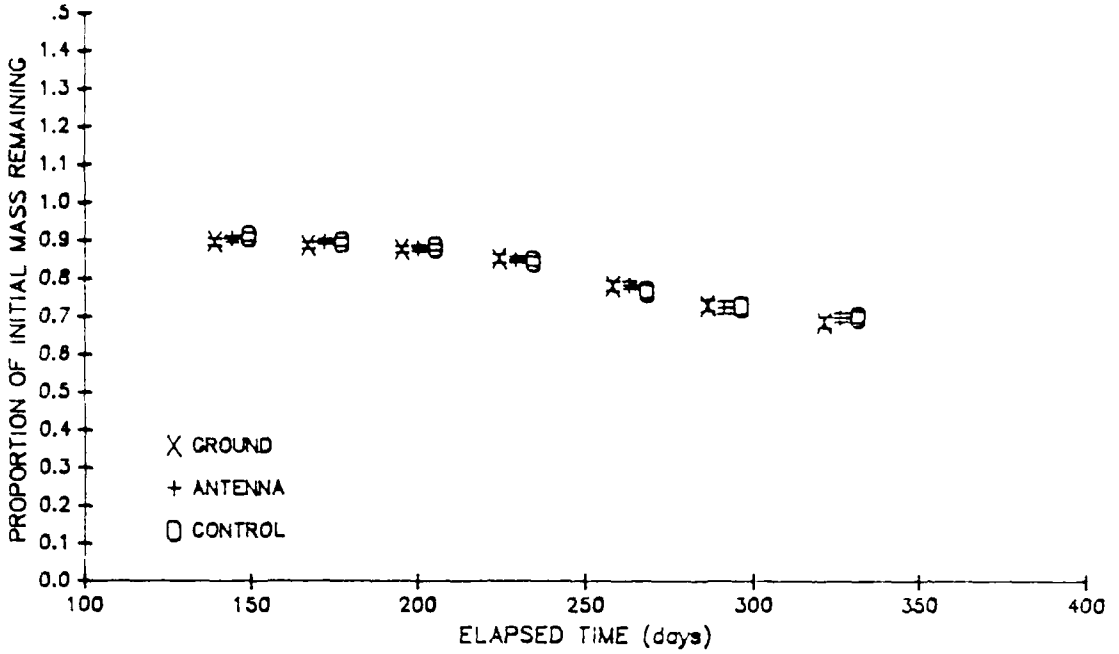

FIGURE 1. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the three plantation subunits during the 1987–1988 experiment.

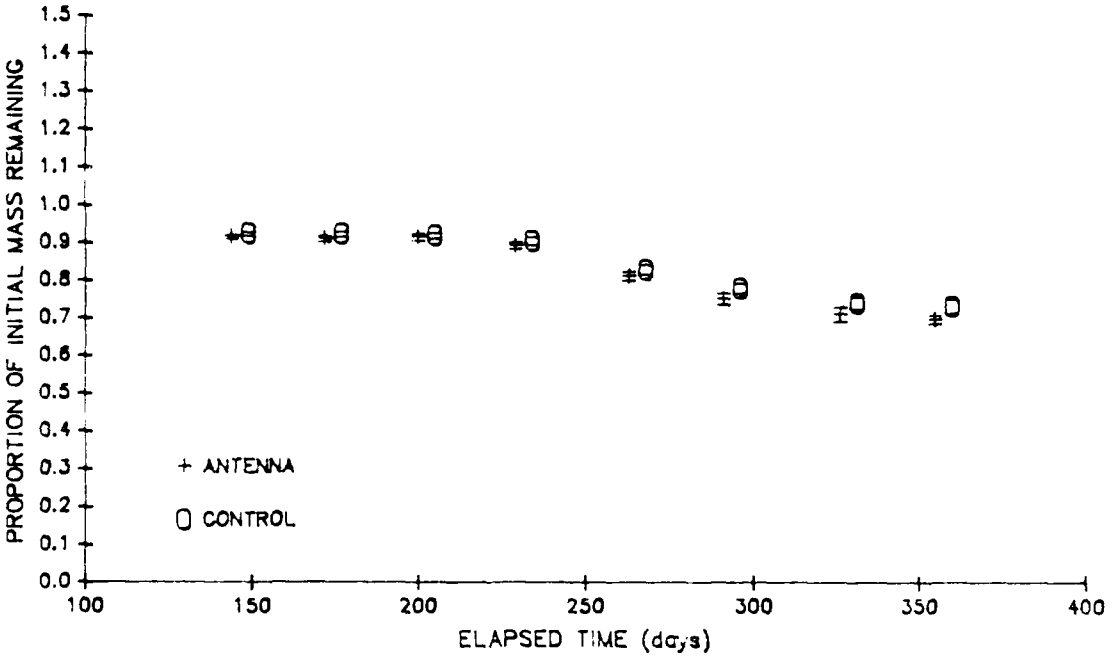

FIGURE 2. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

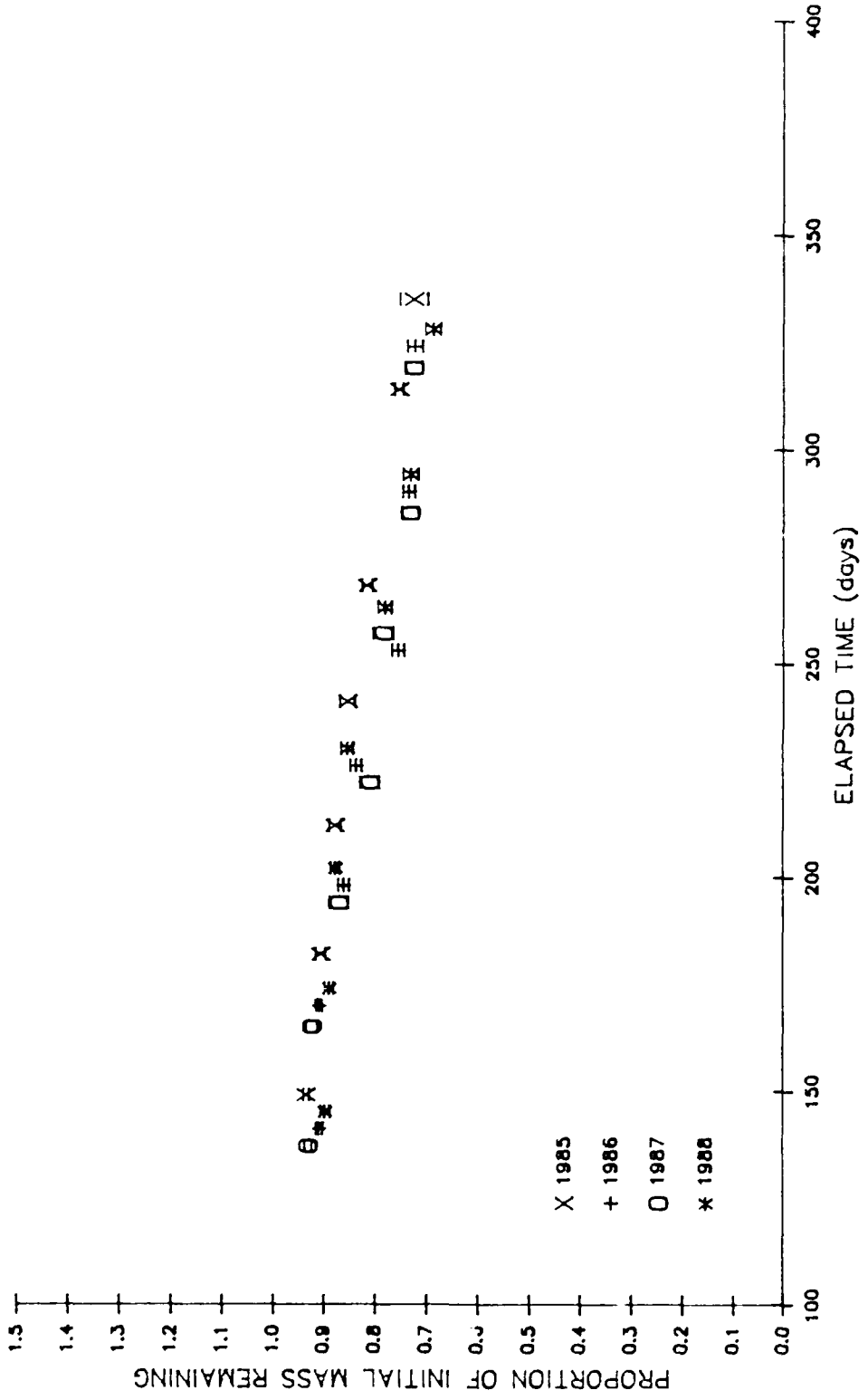

FIGURE 3. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the ground unit plantation during the four consecutive annual experiments completed to date.

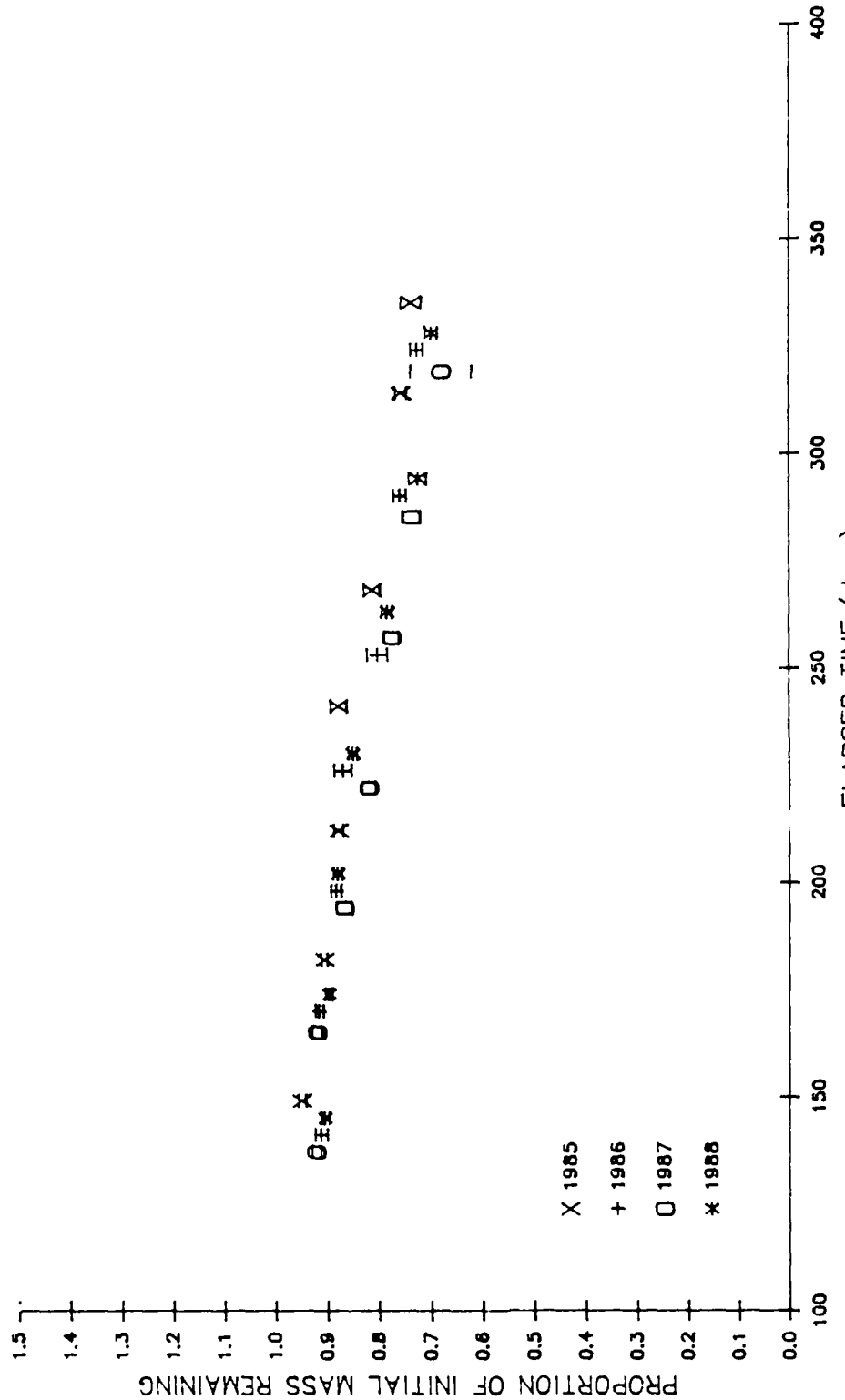

FIGURE 4. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit plantation during the four consecutive annual experiments completed to date.

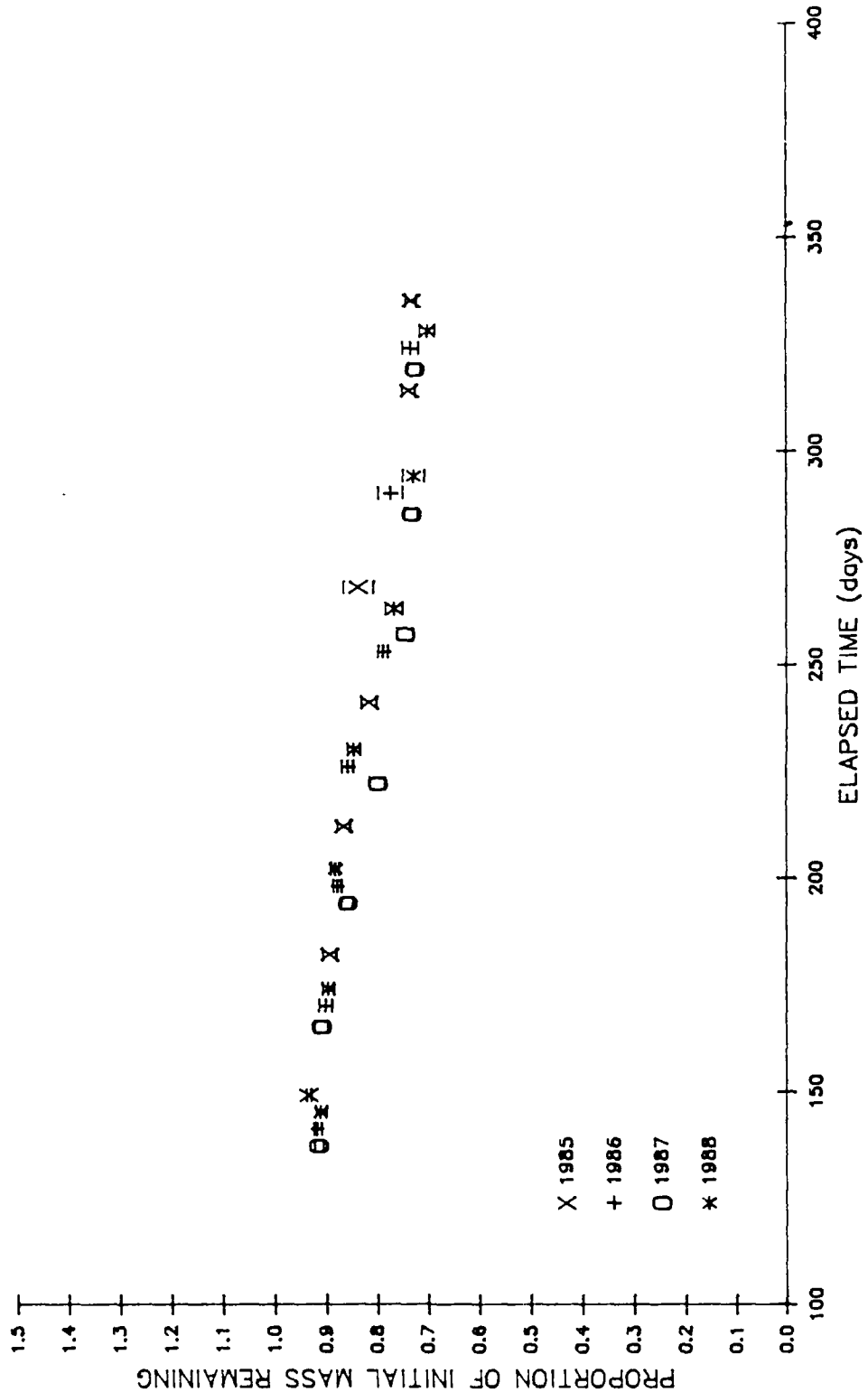

FIGURE 5. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit plantation during the four consecutive annual experiments completed to date.

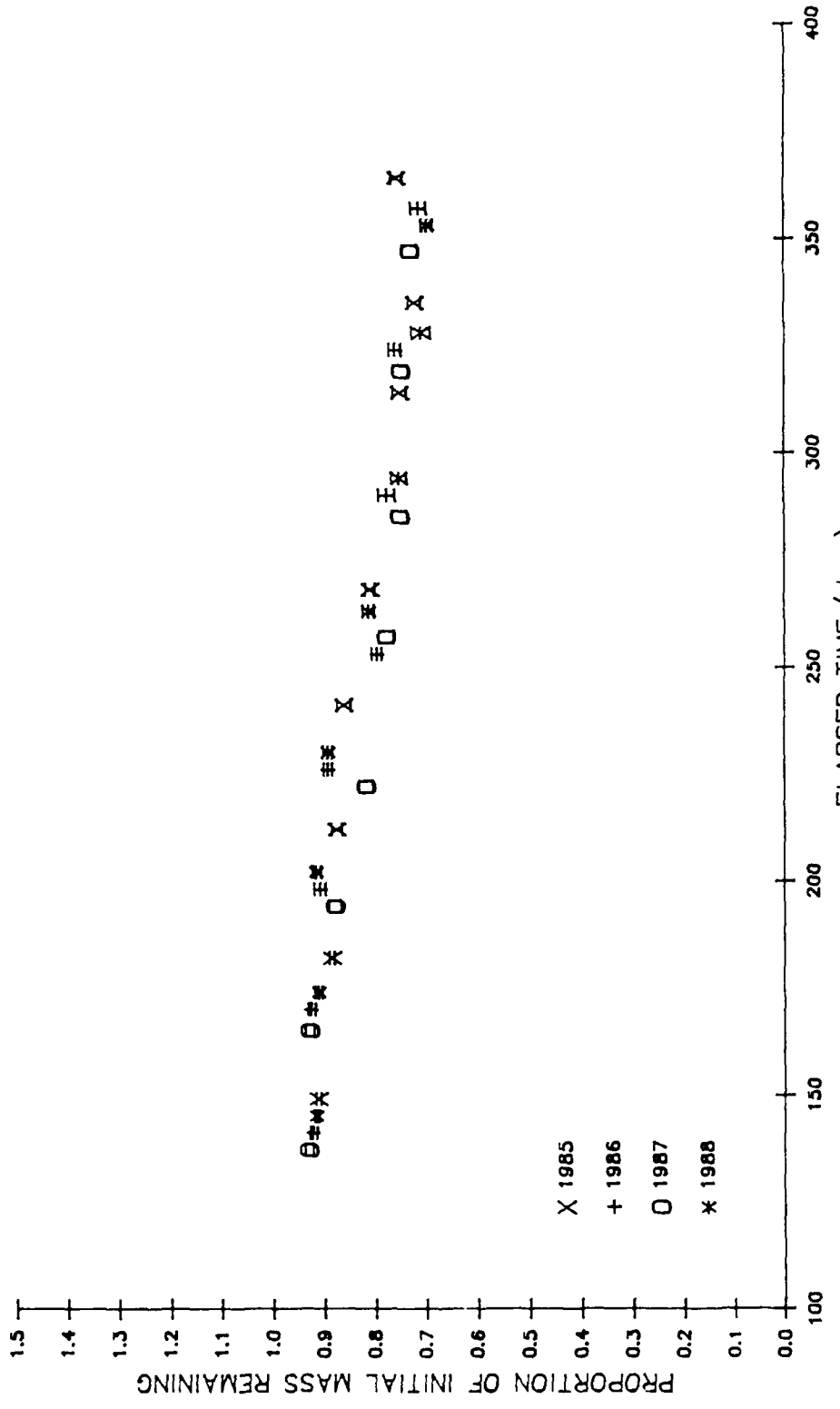

FIGURE 6. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments completed to date.

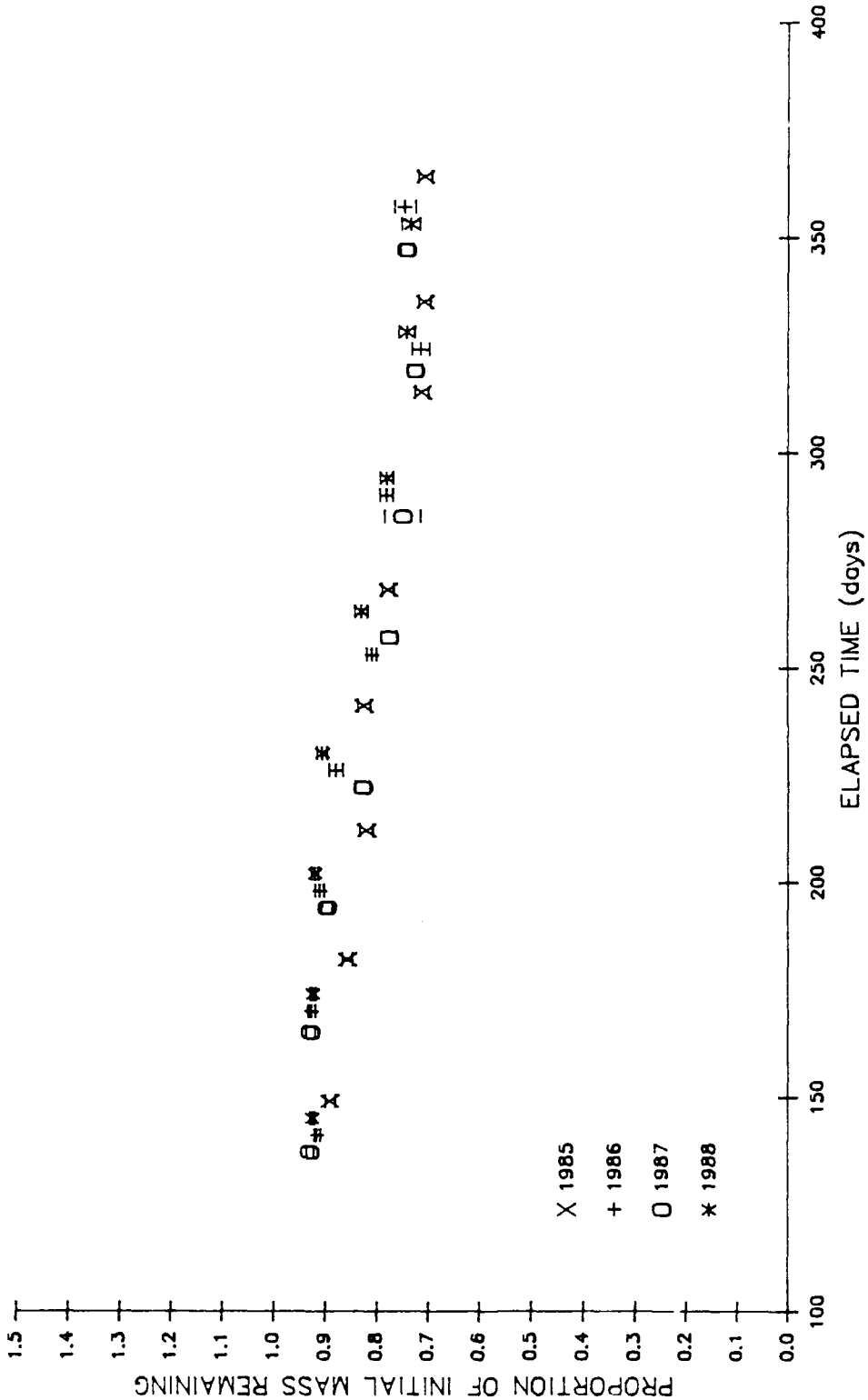

FIGURE 7. Proportion (X) of initial dry matter mass remaining for individual pine fascicle samples retrieved from the control unit hardwood stand during the four consecutive annual experiments completed to date.

striking, and suggest that ANACOV may explain them.

Individual Oak Leaves

Tables 24 and 26 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 25 and 27 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANOVAs, respectively.

No differences were detected in decomposition rate among the three study plantations or between the two hardwood stands. Comparing years in the plantations, 1987 and 1988 samples decomposed fastest and 1986 samples slowest; in the hardwood stands, 1985, 1987, and 1988 samples decomposed faster than 1986 samples. Significant monthly progress occurred in the plantations; except in November, significant monthly progress was also made in the hardwood stands. Detectable differences were very low, below 1.5 percent for yearly, monthly, and subunit mean values.

Figures 8 and 9 present comparisons of monthly progress in dry matter mass loss during the 1987-88 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Corresponding data for the 1986-87, 1985-86, and 1984-85 studies, respectively, were presented as Figures 9-11 in Annual Report 1987. As with the individual pine fascicles, the similarity in oak leaf decomposition among plantation and hardwood stand subunits is encouraging. In 1988, decomposition appears to have proceeded slightly faster in the antenna site hardwood stand than in the control site hardwood stand, but the difference was not significant over all years, as seen by the ANOVA.

Figure 10 presents comparisons of monthly progress in dry matter mass loss during the 1984-85, 1985-86, 1986-87, and 1987-88 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 11 through 14 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands. The significant differences detected by ANOVA are apparent, with the 1986-87 and 1987-88 studies in all three plantations standing out especially. The sampling method for individual oak (and pine) leaves was changed in time for the 1986-87 study, in order to permit truly independent sampling across the study subunits. Instead of collecting multiple tethered leaves in a single envelope from a few locations, larger numbers of envelopes are now collected on each sampling date, each containing only one oak leaf and one pine needle fascicle. One apparent effect of this change in method has been to expose individual leaves and fascicles more uniformly to weathering, because there is less opportunity now for individuals within an envelope to protect one another from the elements. It should be noted that individual

Table 24. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual oak** leaves in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	53.42		444.74	0.0000	0.69
Year	3		10.04	306.42	0.0000	
Month	6		43.73	667.46	0.0000	
Plantation	2		0.05	2.17	0.1146	
Error	2209	24.12				
Corrected Total	2220	77.54				

Table 25. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 24.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	7
1985	1.10	0.004	0.71	1985						
1986	1.16	0.004	0.68	1986				*		
1987	0.99	0.005	0.99	1987				*	*	
1988	1.01	0.005	0.97	1988				*	*	
Month					1	2	3	4	5	6
May	1.29	0.006	0.91	May						
June	1.20	0.006	0.98	June	*					
July	1.14	0.006	1.03	July	*	*				
August	1.06	0.006	1.11	Aug	*	*	*			
September	0.98	0.006	1.20	Sept	*	*	*	*		
October	0.92	0.006	1.28	Oct	*	*	*	*	*	
November	0.87	0.006	1.35	Nov	*	*	*	*	*	*
Plantation								G		A
Ground	1.06	0.004	0.74	Ground						
Antenna	1.06	0.004	0.74	Antenna						
Control	1.07	0.004	0.73	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

Table 26. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual oak** leaves in the two **hardwood stand** subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	28.30		435.65	0.0000	0.74
Year	3		0.83	46.84	0.0001	
Month	7		27.23	658.72	0.0000	
Hardwood Stand	1		0.01	2.23	0.1355	
Error	1684	9.94				
Corrected Total	1695	38.24				

Table 27. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 26.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5	6	7	
1985	1.12	0.004	0.70	1985							
1986	1.17	0.004	0.67	1986				*			
1987	1.13	0.004	0.69	1987				*	*		
1988	1.13	0.004	0.69	1988					*		
Month					1	2	3	4	5	6	7
May	1.31	0.005	0.75	May							
June	1.27	0.005	0.77	June	*						
July	1.25	0.005	0.78	July	*	*					
August	1.19	0.005	0.82	Aug	*	*	*				
September	1.11	0.005	0.88	Sept	*	*	*	*			
October	1.03	0.005	0.95	Oct	*	*	*	*	*		
November	0.97	0.005	1.01	Nov	*	*	*	*	*	*	
December	0.97	0.005	1.01	Dec	*	*	*	*	*	*	
Hardwood Stand								A			
Antenna	1.14	0.003	0.52	Antenna							
Control	1.14	0.003	0.52	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

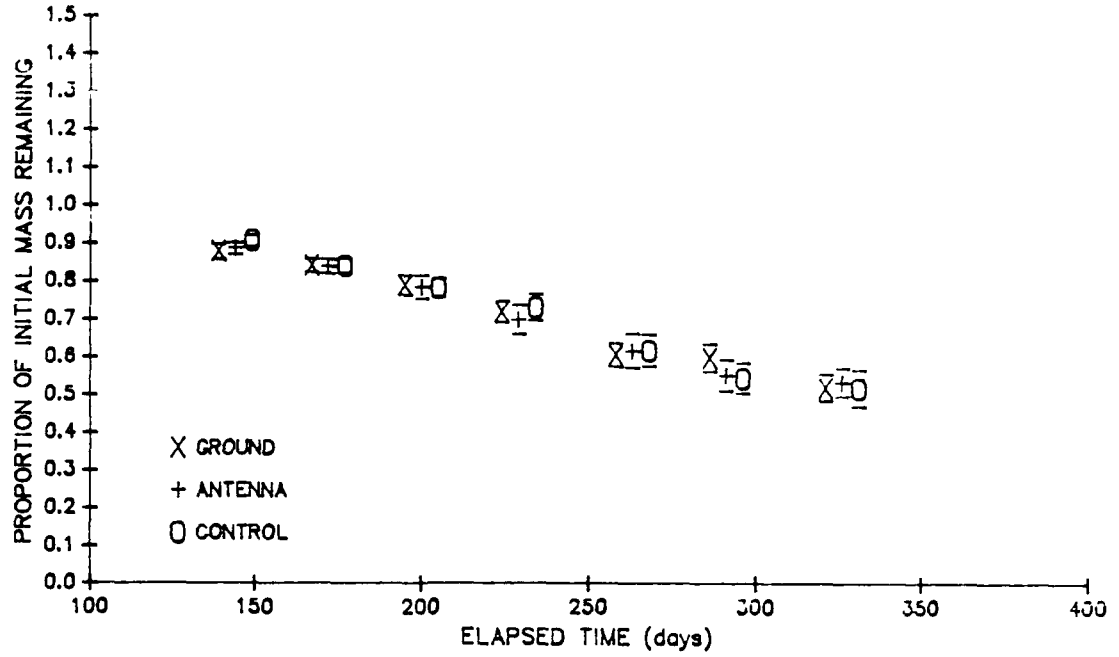

FIGURE 8. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the three plantation subunits during the 1987–1988 experiment.

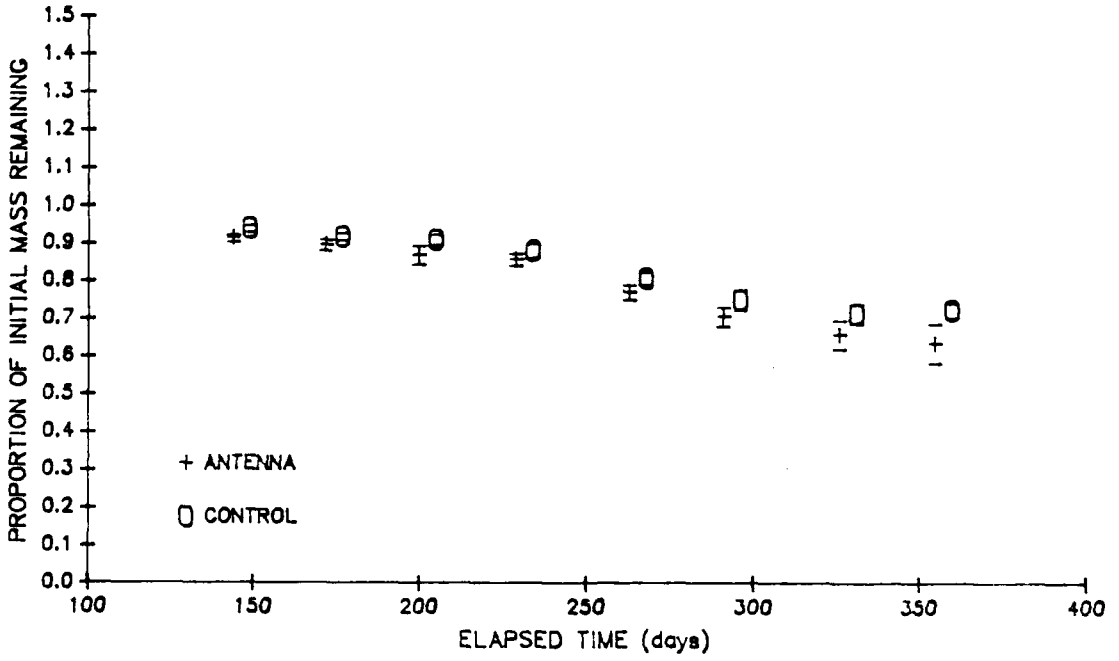

FIGURE 9. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

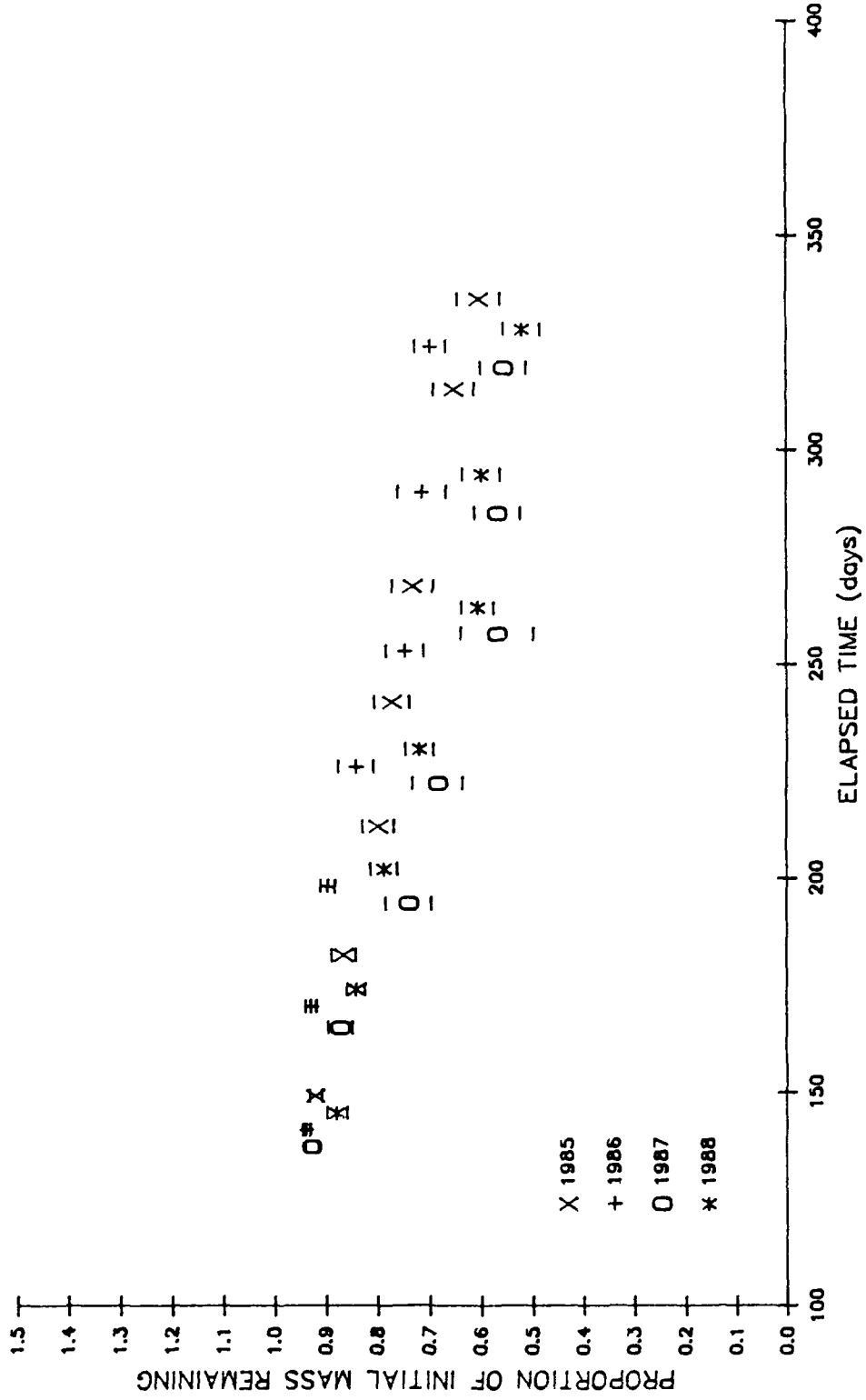

FIGURE 10. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the ground unit plantation during the four consecutive annual experiments completed to date.

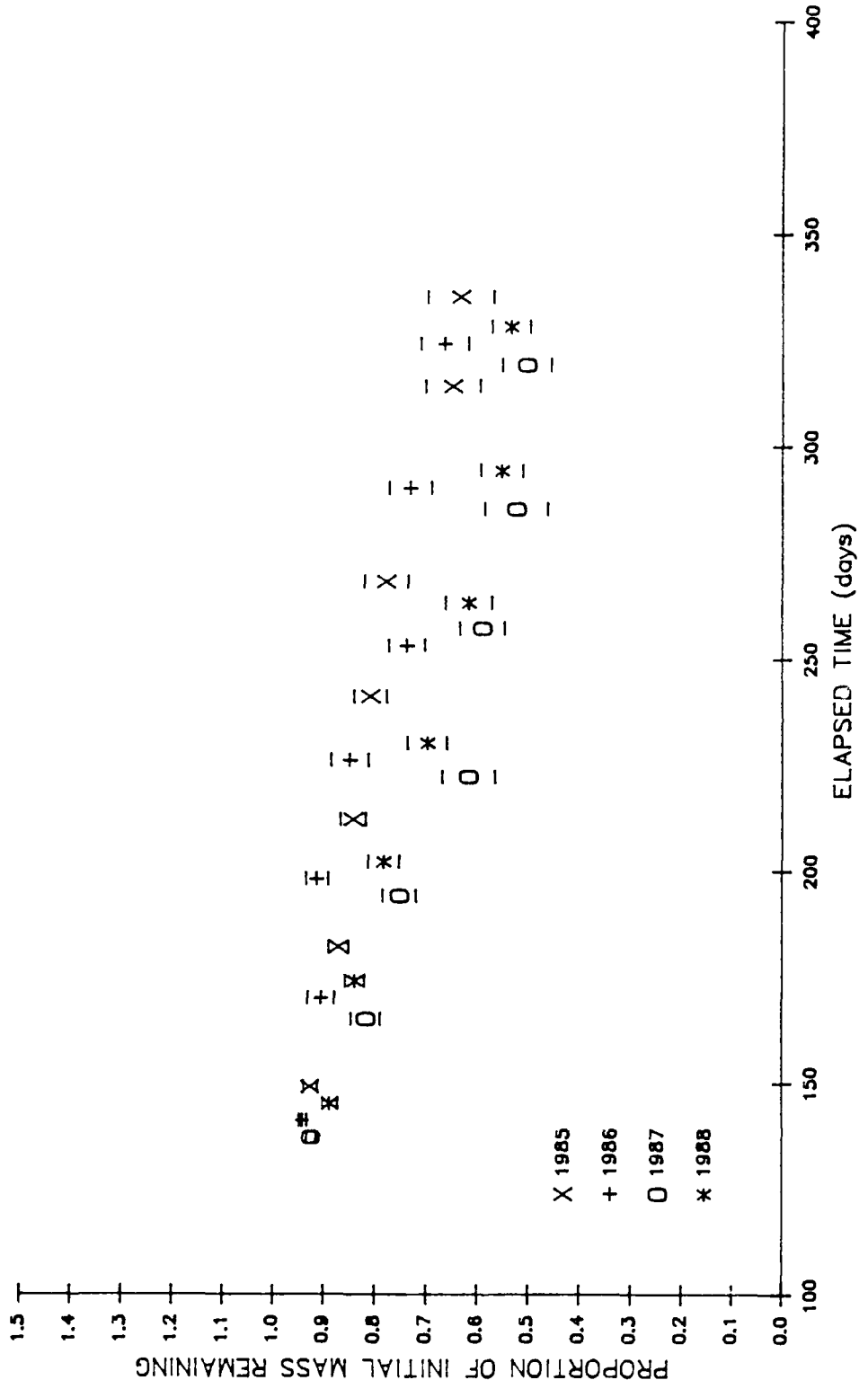

FIGURE 11. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit plantation during the four consecutive annual experiments completed to date.

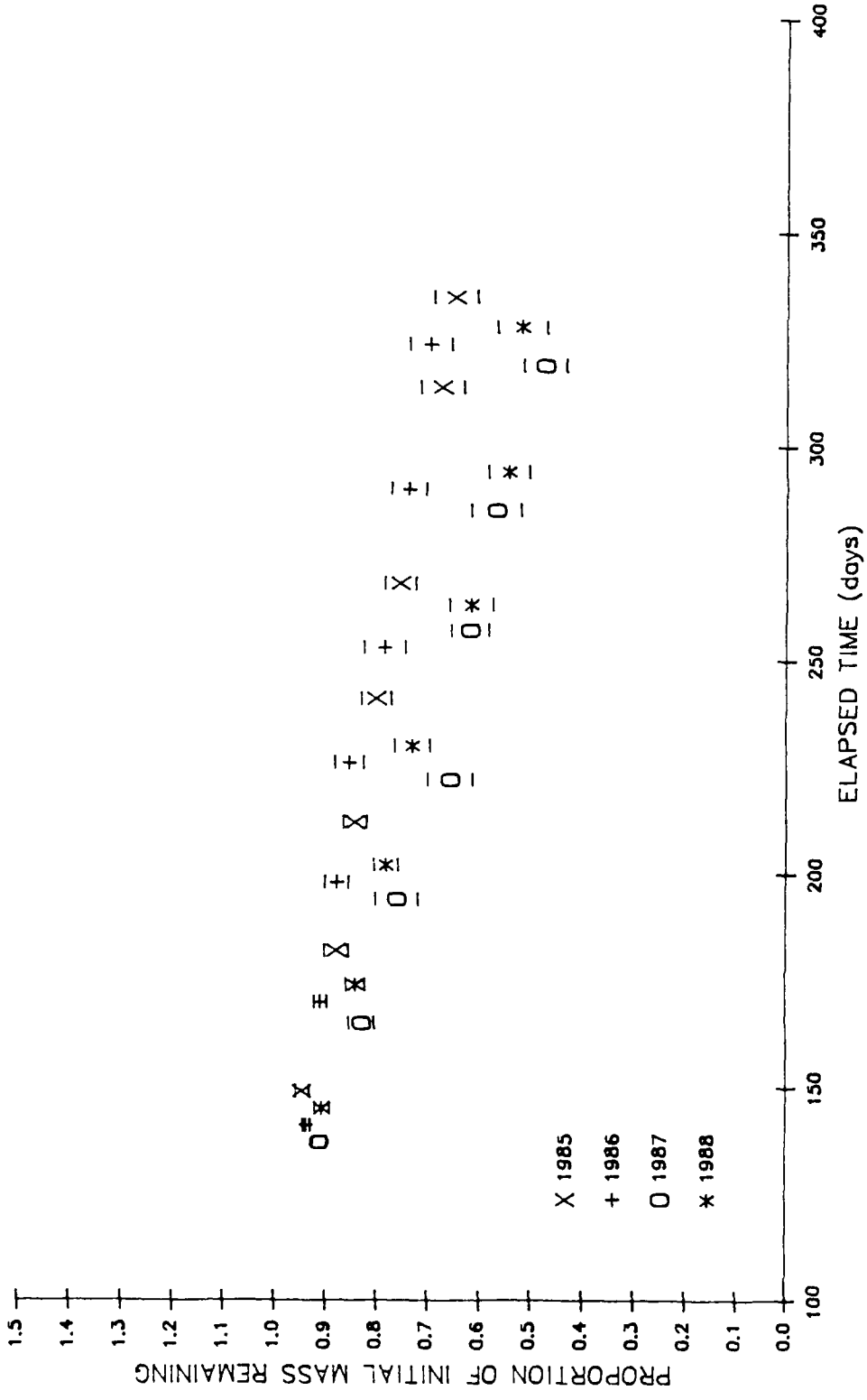

FIGURE 12. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit plantation during the four consecutive annual experiments completed to date.

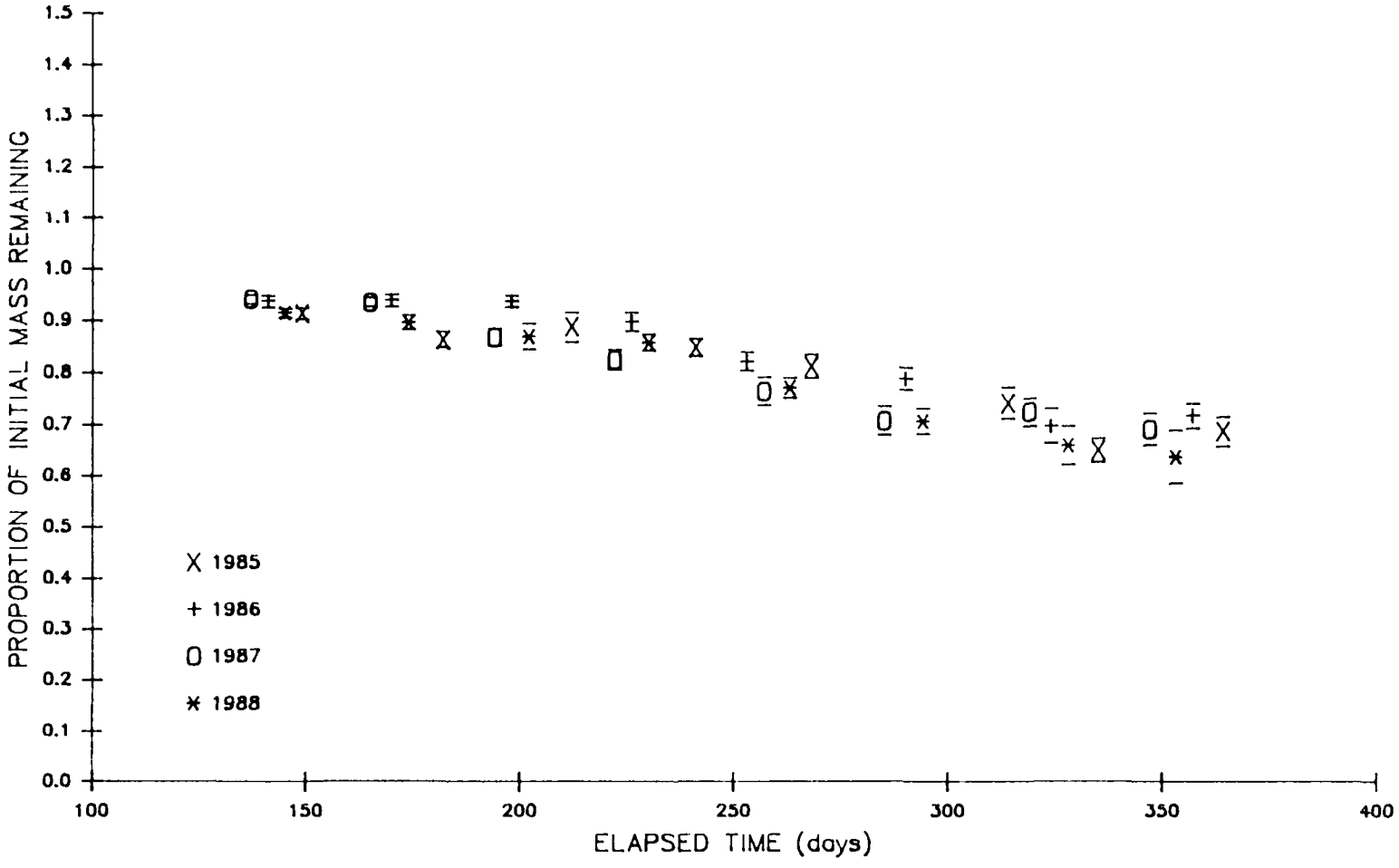

FIGURE 13. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments completed to date.

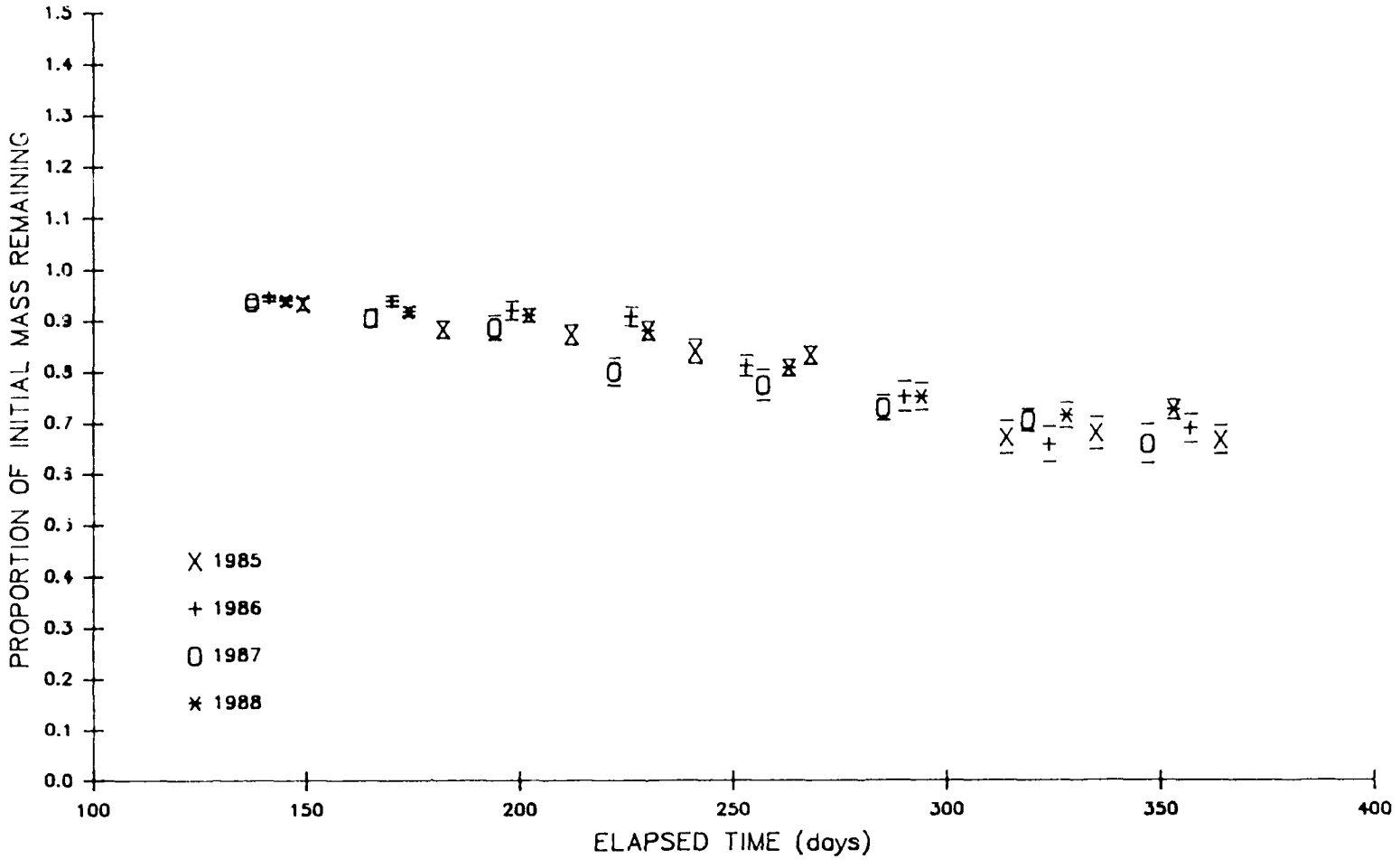

FIGURE 14. Proportion (X) of initial dry matter mass remaining for individual oak leaf samples retrieved from the control unit hardwood stand during the four consecutive annual experiments completed to date.

pine fascicles placed in the three plantations also decomposed more rapidly during the 1986-87 and 1987-88 studies than in earlier years. The differences between years detected by ANOVA for mass loss from individual oak leaves and pine needles in the hardwood stands do not fit the same pattern. However, samples within the hardwood stands are not exposed to the same intensity of weathering as those in the plantation environment.

ANOVA Results - Bulk Leaf Litter Samples

Bulk Pine Needle Litter

Tables 28 and 30 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 29 and 31 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand ANOVAs.

Bulk pine needles decomposed faster in the ground and control plantations than in the antenna plantation. Although no difference was detected between the control and antenna hardwood stands, the p level of 0.0597 was very close to the null hypothesis rejection level of $\alpha = 0.05$. Comparing years in the plantations, 1985 samples decomposed fastest and 1987 and 1988 samples slowest; in the hardwood stands, 1985 samples decomposed fastest and 1988 samples slowest. Significant monthly progress occurred in the plantations, while monthly progress in the hardwood stands occurred from May through September. Detectable differences were extremely low, below 1 percent of the yearly, monthly and subunit mean values. This accounts for some of the very small differences between mean values which are nonetheless statistically detected.

Figures 15 and 16 present comparisons of monthly progress in dry matter mass loss during the 1987-88 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Corresponding data for the 1986-87, 1985-86, and 1984-85 studies, respectively, were presented as Figures 25-27 in Annual Report 1987. As with the individual pine fascicle samples, the general similarity among plantation and hardwood stand subunits is encouraging, and suggests that ANACOV may explain the differences detected by ANOVA. The significant differences detected between plantation subunits by ANOVA would be difficult to anticipate from the figures alone.

Figure 17 presents comparisons of monthly progress in dry matter mass loss during the 1984-85, 1985-86, 1986-87, and 1987-88 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 17 through 21 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the significant differences detected by ANOVA are small, suggesting that ANACOV may explain them.

Table 28. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	4.48		344.84	0.0000	0.89
Year	3		0.18	51.03	0.0001	
Month	6		4.25	600.18	0.0000	
Plantation	2		0.05	19.51	0.0001	
Error	492	0.58				
Corrected Total	503	5.06				

Table 29. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 23.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7			
1985	1.12	0.003	0.52	1985						
1986	1.15	0.003	0.51	1986	*					
1987	1.17	0.003	0.50	1987	*	*				
1988	1.16	0.003	0.51	1988	*	*				
Month					1	2	3	4	5	6
May	1.27	0.004	0.62	May						
June	1.24	0.004	0.63	June	*					
July	1.21	0.004	0.65	July	*	*				
August	1.17	0.004	0.67	Aug	*	*	*			
September	1.10	0.004	0.71	Sept	*	*	*	*		
October	1.04	0.004	0.75	Oct	*	*	*	*	*	
November	1.02	0.004	0.77	Nov	*	*	*	*	*	*
Plantation							G	A		
Ground	1.14	0.003	0.52	Ground						
Antenna	1.16	0.003	0.51	Antenna			*			
Control	1.14	0.003	0.52	Control				*		

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

Table 30. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	4.41		384.98	0.0000	0.92
Year	3		0.23	75.05	0.0001	
Month	7		4.17	572.27	0.0000	
Hardwood Stand	1		0.00	3.57	0.0597	
Error	370	0.38				
Corrected Total	381	4.79				

Table 31. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 30.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5	6	7	
1985	1.09	0.003	0.54	1985							
1986	1.15	0.003	0.51	1986				*			
1987	1.14	0.003	0.52	1987				*			
1988	1.16	0.003	0.51	1988				*	*	*	
Month					1	2	3	4	5	6	7
May	1.29	0.005	0.76	May							
June	1.25	0.005	0.78	June	*						
July	1.22	0.005	0.80	July	*	*					
August	1.18	0.005	0.83	Aug	*	*	*				
September	1.08	0.005	0.91	Sept	*	*	*	*			
October	1.04	0.005	0.94	Oct	*	*	*	*	*		
November	1.02	0.005	0.96	Nov	*	*	*	*	*		
December	1.01	0.005	0.97	Dec	*	*	*	*	*	*	
Hardwood Stand								C			
Antenna	1.13	0.002	0.35	Antenna							
Control	1.14	0.002	0.34	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

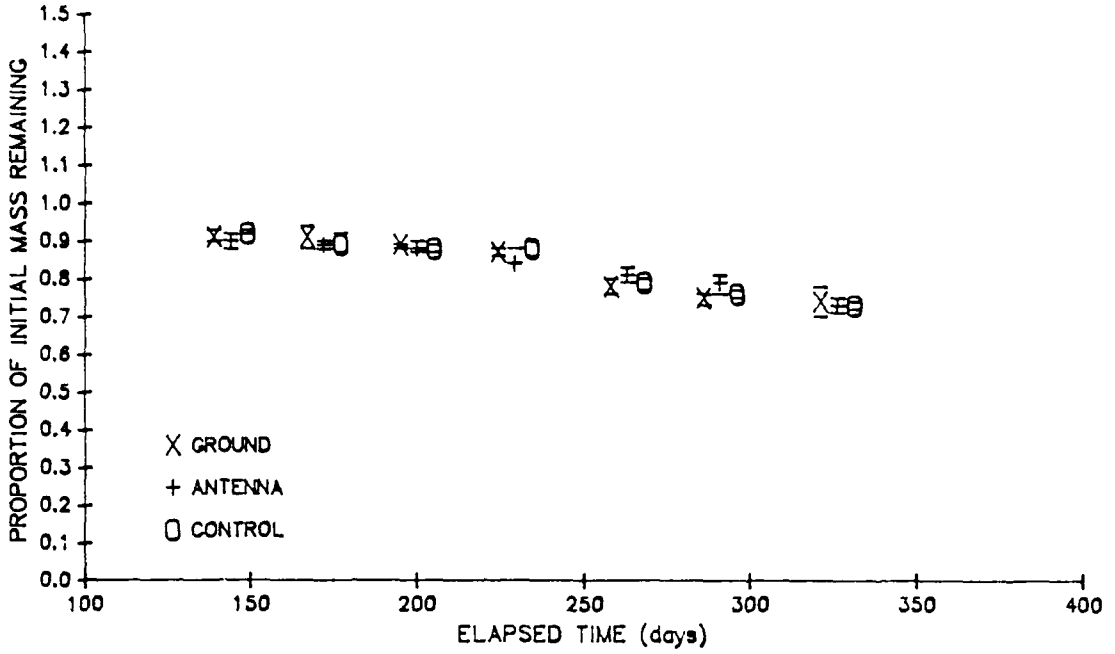

FIGURE 15. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the three plantation subunits during the 1987–1988 experiment.

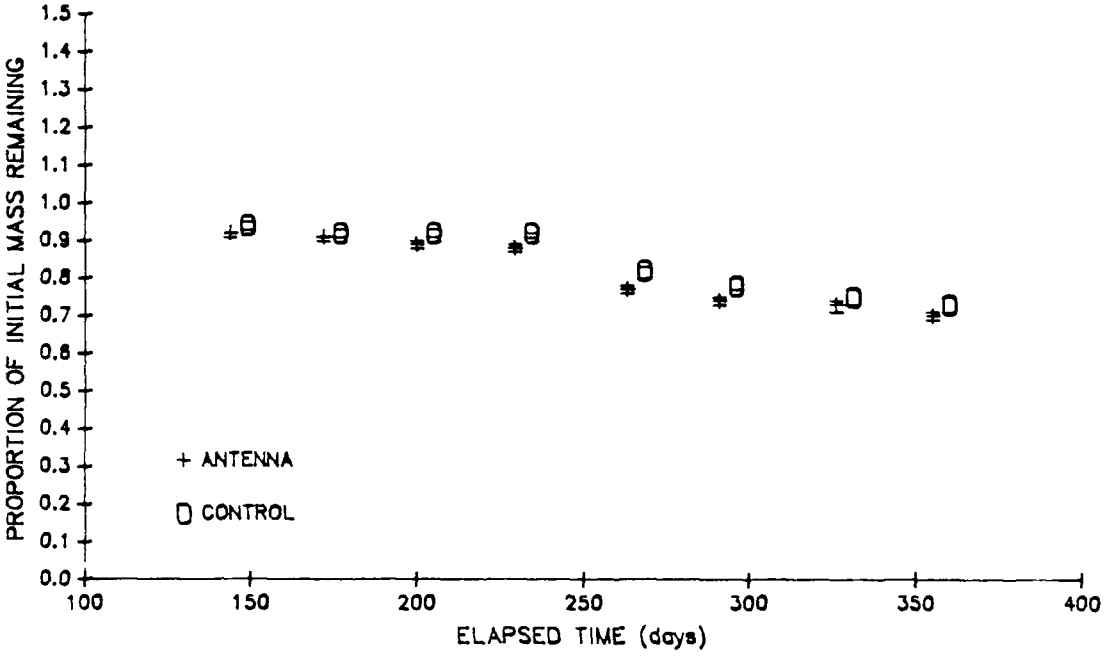

FIGURE 16. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

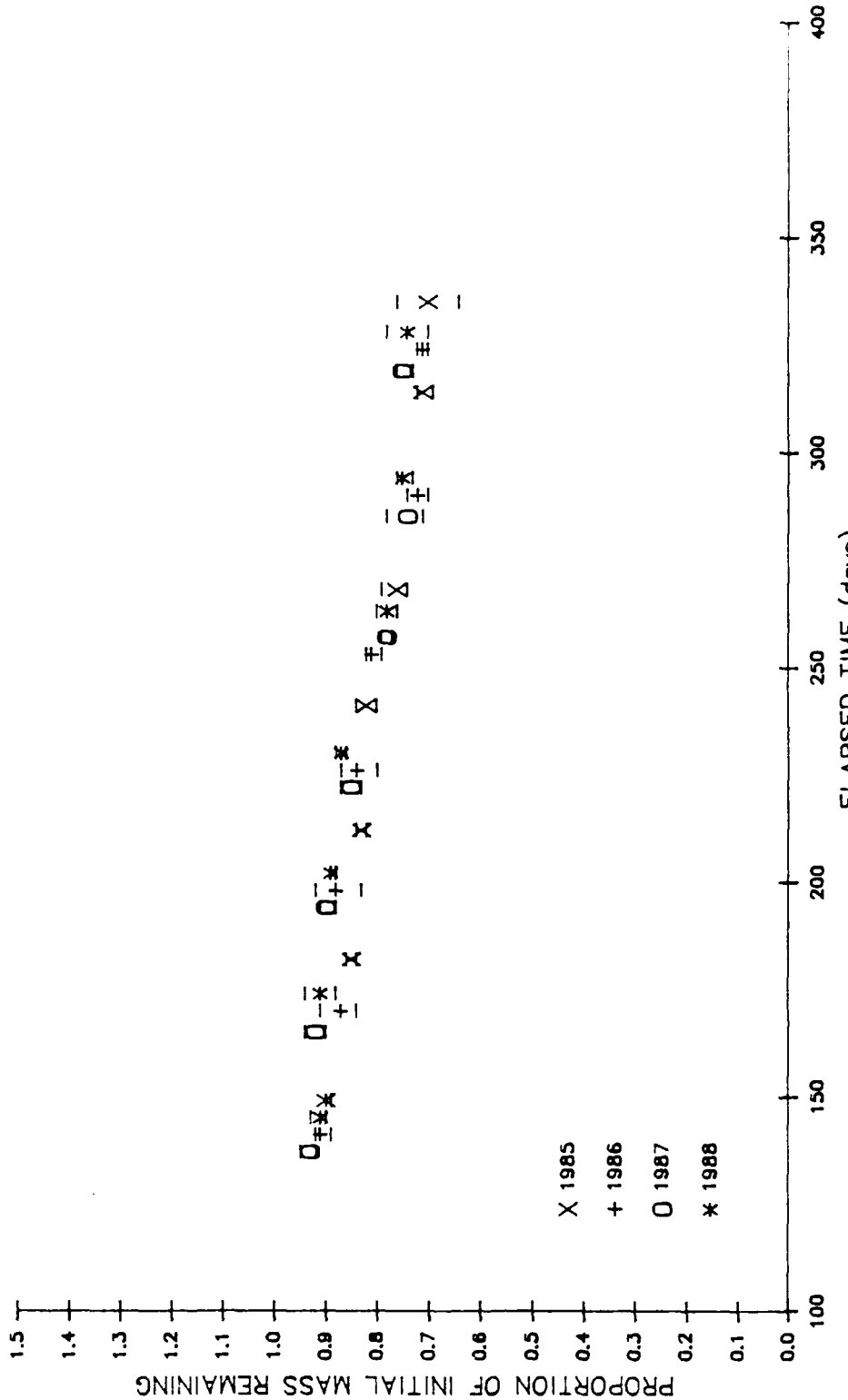

FIGURE 17. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the ground unit plantation during the four consecutive annual experiments completed to date.

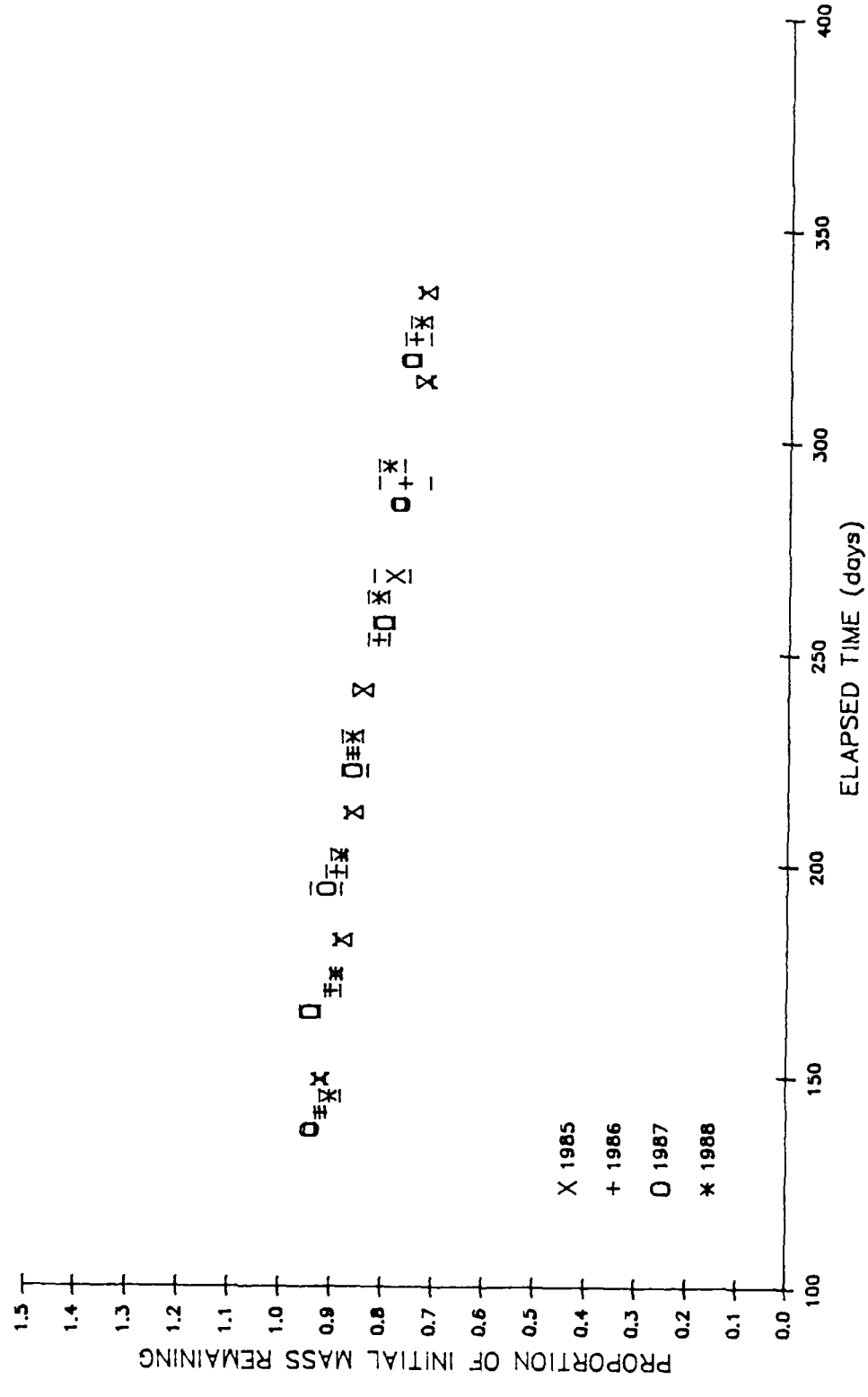

FIGURE 18. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit plantation during the four consecutive annual experiments completed to date.

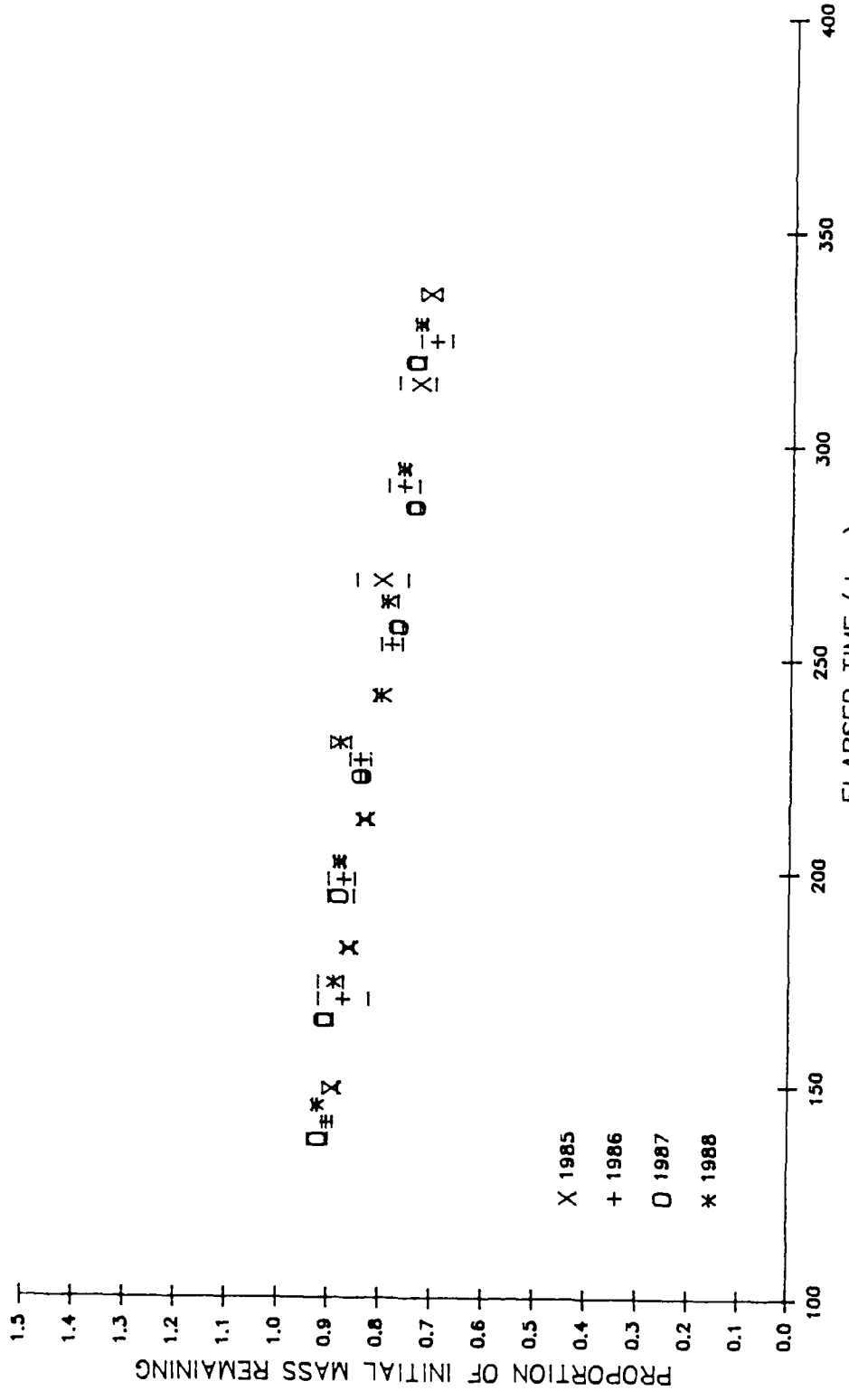

FIGURE 19. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit plantation during the four consecutive annual experiments completed to date.

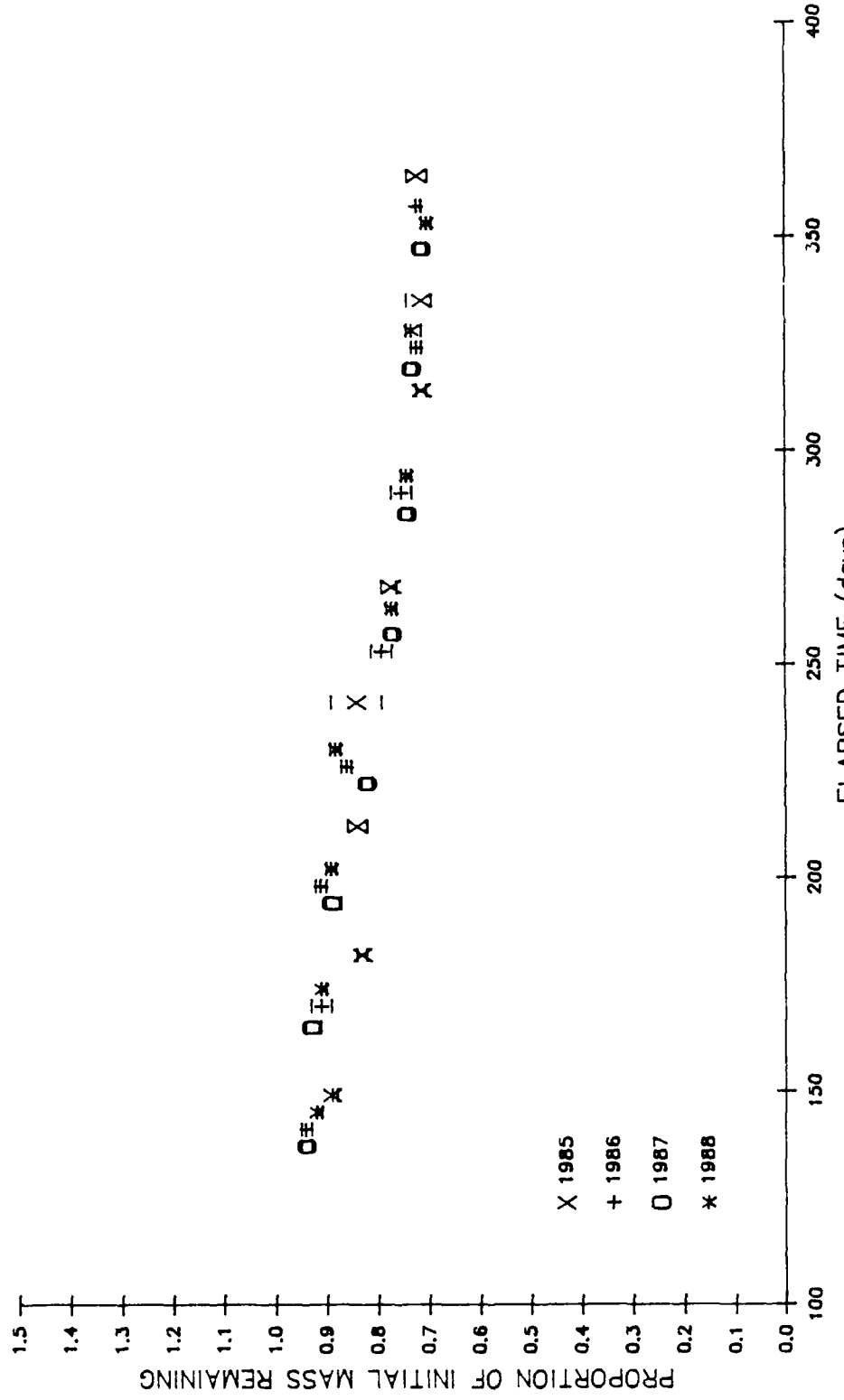

FIGURE 20. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments completed to date.

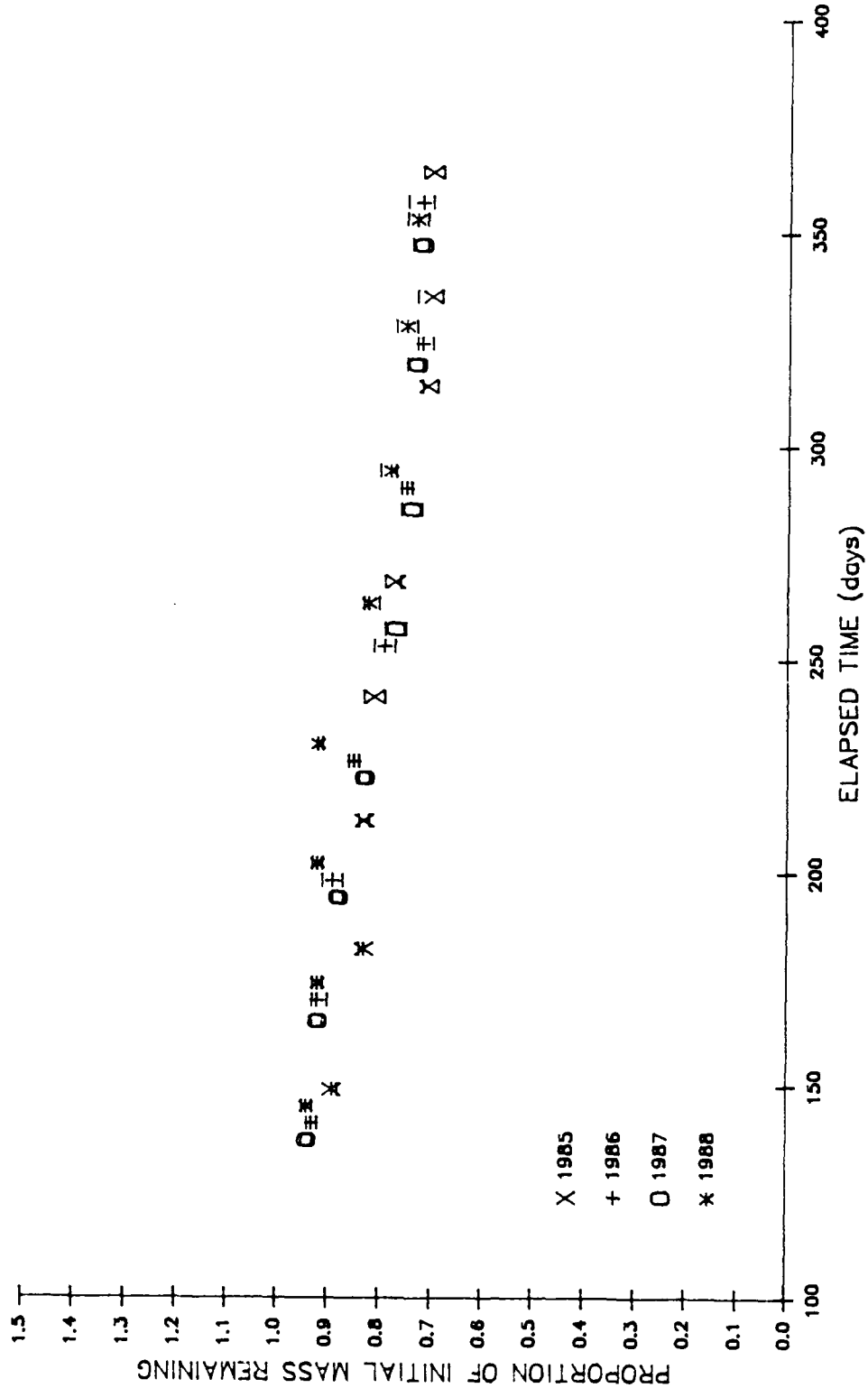

FIGURE 21. Proportion (X) of initial dry matter mass remaining for bulk pine needle samples retrieved from the control unit hardwood stand during the four consecutive annual experiments completed to date.

Bulk Oak Leaf Litter

Tables 32 and 34 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 33 and 35 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANOVAs, respectively.

Bulk oak leaf samples decomposed faster in the ground and antenna plantations than in the control plantation. ANOVA detected no difference in the rate of decomposition between the two hardwood stands. Comparing years in plantations, 1985 samples decomposed faster than either 1986 or 1987 samples, and 1988 samples decomposed faster than 1986 samples. In the hardwood stands, 1985 samples decomposed fastest and 1986 samples slowest. Significant monthly progress occurred in the plantations; significant monthly progress was made in the hardwood stands, except during May and October. Detectable differences were extremely low, below 1 percent for yearly and subunit mean values, and below 1.5 percent for monthly mean values.

Figures 22 and 23 present comparisons of monthly dry matter mass loss progress during the 1986-87 study on the plantation and hardwood stand subunits, respectively. Means representing the raw data are plotted between bars depicting their associated 95 percent confidence intervals. Corresponding data for the 1986-87, 1985-86, and 1984-85 studies, respectively, were presented as Figures 33-35 in the Annual Report 1987. As with the bulk pine samples, the similarity in bulk oak sample decomposition among plantation and hardwood stand subunits is encouraging; the significant differences detected by ANOVA would be hard to anticipate from the figures alone.

Figure 24 presents comparisons of monthly progress in dry matter mass loss during the 1984-85, 1985-86, 1986-87, and 1987-88 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 25 through 28 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the significant differences detected by ANOVA would be difficult to anticipate from the figures alone.

Bulk Maple Leaf Litter

Tables 36 and 38 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 37 and 39 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand ANOVAs.

Bulk maple leaves decomposed faster in the ground and antenna plantations than in the control plantation. Samples also decomposed more rapidly in the antenna hardwood stand than in the control hardwood stand. Comparing years in the plantation

Table 32. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	6.31		197.97	0.0000	0.82
Year	3		0.11	13.02	0.0001	
Month	6		6.15	353.41	0.0000	
Plantation	2		0.05	9.10	0.0001	
Error	489	1.42				
Corrected Total	500	7.73				

Table 33. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 32.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	7
1985	1.13	0.005	0.87	1985						
1986	1.17	0.005	0.84	1986				*		
1987	1.16	0.005	0.84	1987				*		
1988	1.14	0.005	0.86	1988					*	
Month					1	2	3	4	5	6
May	1.31	0.006	0.90	May						
June	1.26	0.006	0.93	June	*					
July	1.22	0.006	0.96	July	*	*				
August	1.16	0.006	1.01	Aug	*	*	*			
September	1.09	0.006	1.08	Sept	*	*	*	*		
October	1.03	0.006	1.14	Oct	*	*	*	*	*	
November	0.99	0.006	1.19	Nov	*	*	*	*	*	*
Plantation							G		A	
Ground	1.14	0.004	0.69	Ground						
Antenna	1.14	0.004	0.69	Antenna						
Control	1.17	0.004	0.67	Control			*		*	

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

Table 34. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	6.55		264.10	0.0000	0.89
Year	3		0.23	33.70	0.0000	
Month	7		6.32	400.44	0.0001	
Hardwood Stand	1		0.00	1.05	0.3065	
Error	371	0.84				
Corrected Total	382	7.39				

Table 35. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 34.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5	6	7	
1985	1.13	0.005	0.87	1985							
1986	1.20	0.005	0.82	1986				*			
1987	1.17	0.005	0.84	1987				*	*		
1988	1.17	0.005	0.84	1988				*	*		
Month					1	2	3	4	5	6	7
May	1.33	0.007	1.03	May							
June	1.31	0.007	1.05	June							
July	1.28	0.007	1.07	July	*	*					
August	1.23	0.007	1.12	Aug	*	*	*				
September	1.13	0.007	1.21	Sept	*	*	*	*			
October	1.05	0.007	1.31	Oct	*	*	*	*	*		
November	1.02	0.007	1.35	Nov	*	*	*	*	*		
December	0.99	0.007	1.39	Dec	*	*	*	*	*	*	*
Hardwood Stand								A			
Antenna	1.17	0.005	0.84	Antenna							
Control	1.17	0.005	0.84	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

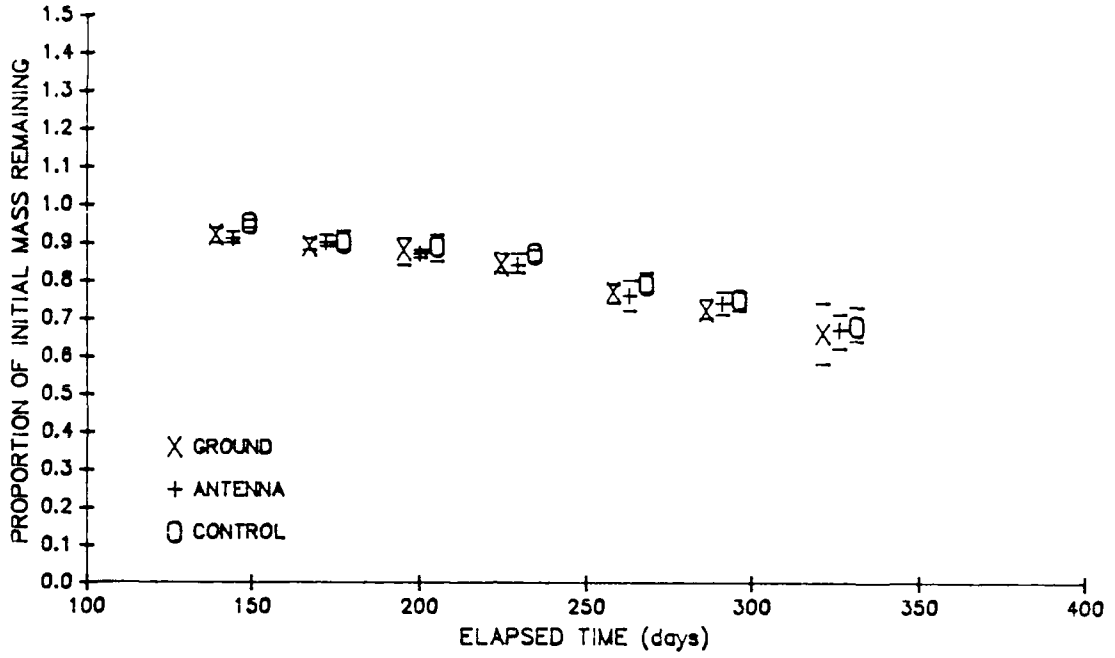

FIGURE 22. Proportion (X) of initial dry ...atter mass remaining for bulk oak leaf samples retrieved from the three plantation subunits during the 1987–1988 experiment.

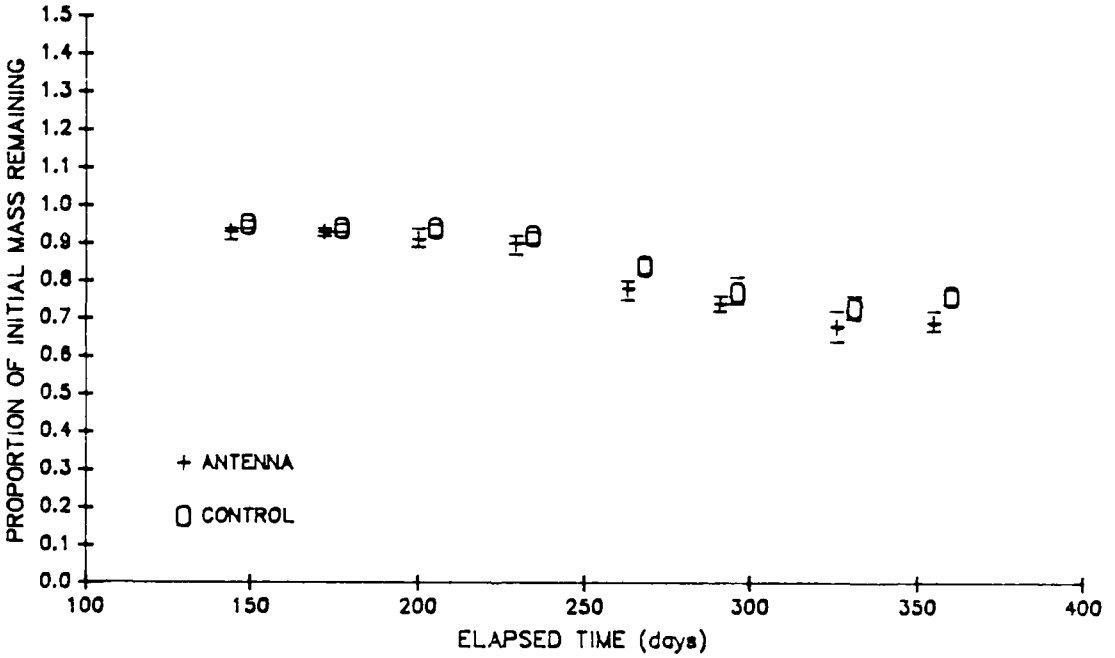

FIGURE 23. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

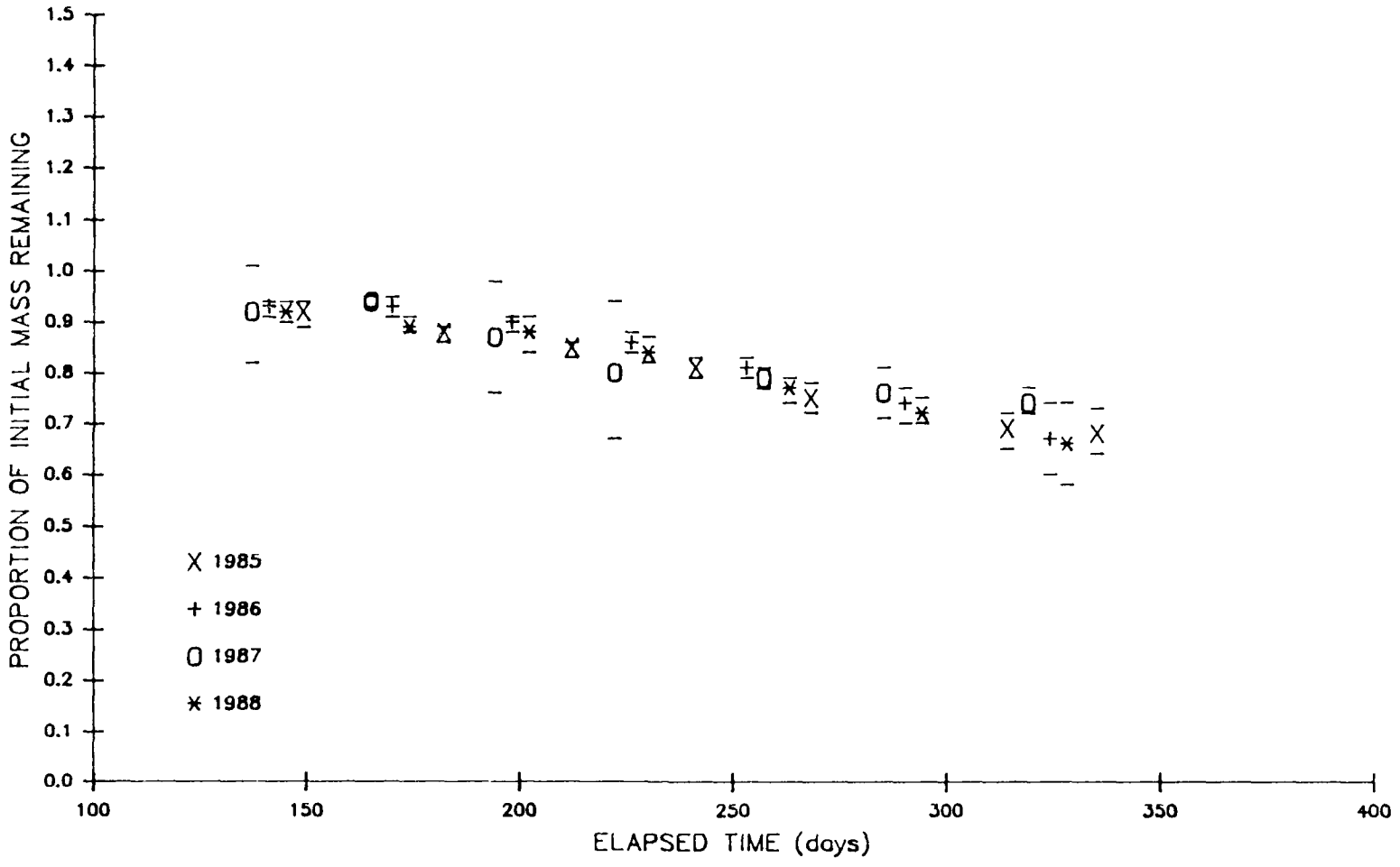

FIGURE 24. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the ground unit plantation during the four consecutive annual experiments completed to date.

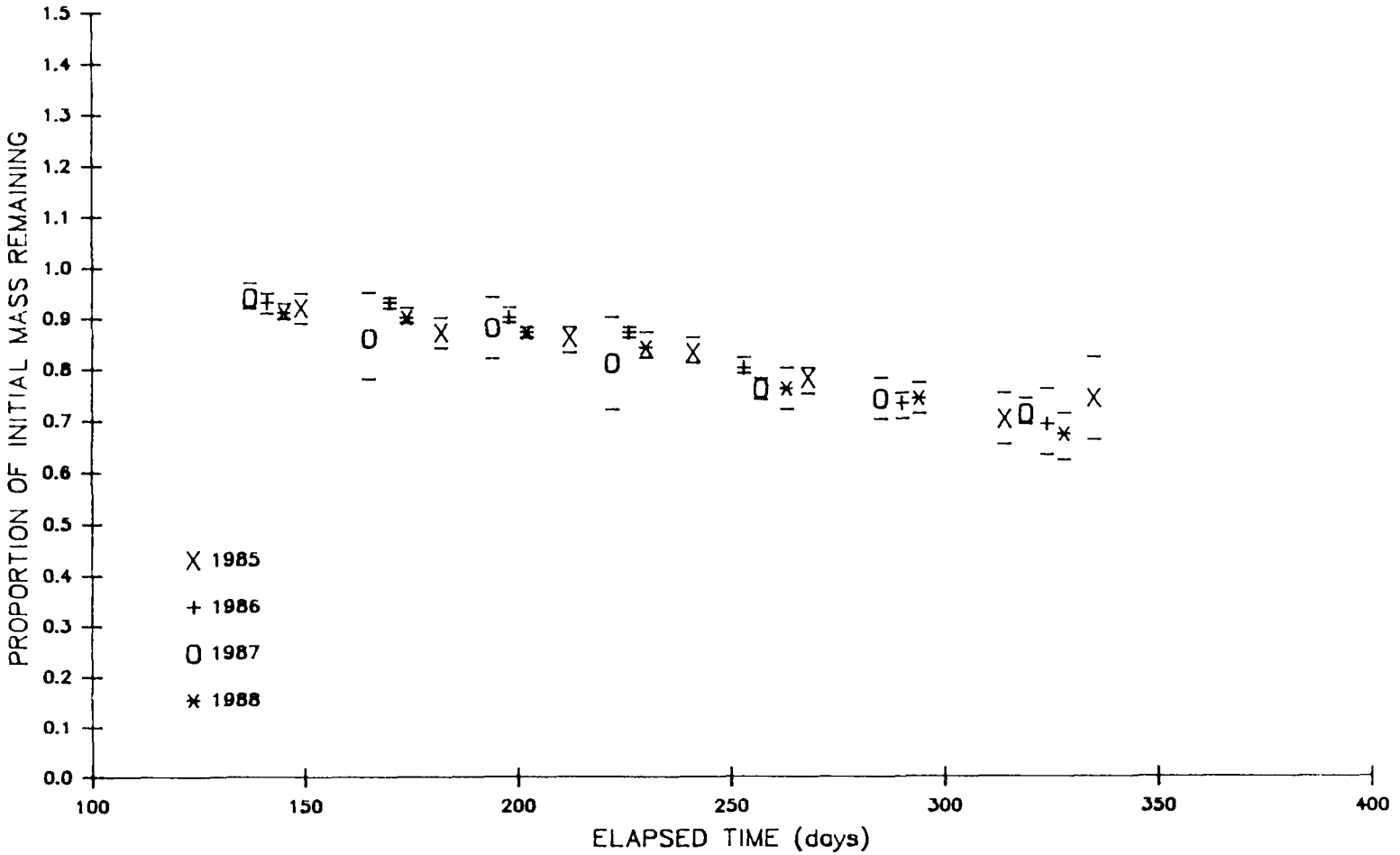

FIGURE 25. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit plantation during the four consecutive annual experiments completed to date.

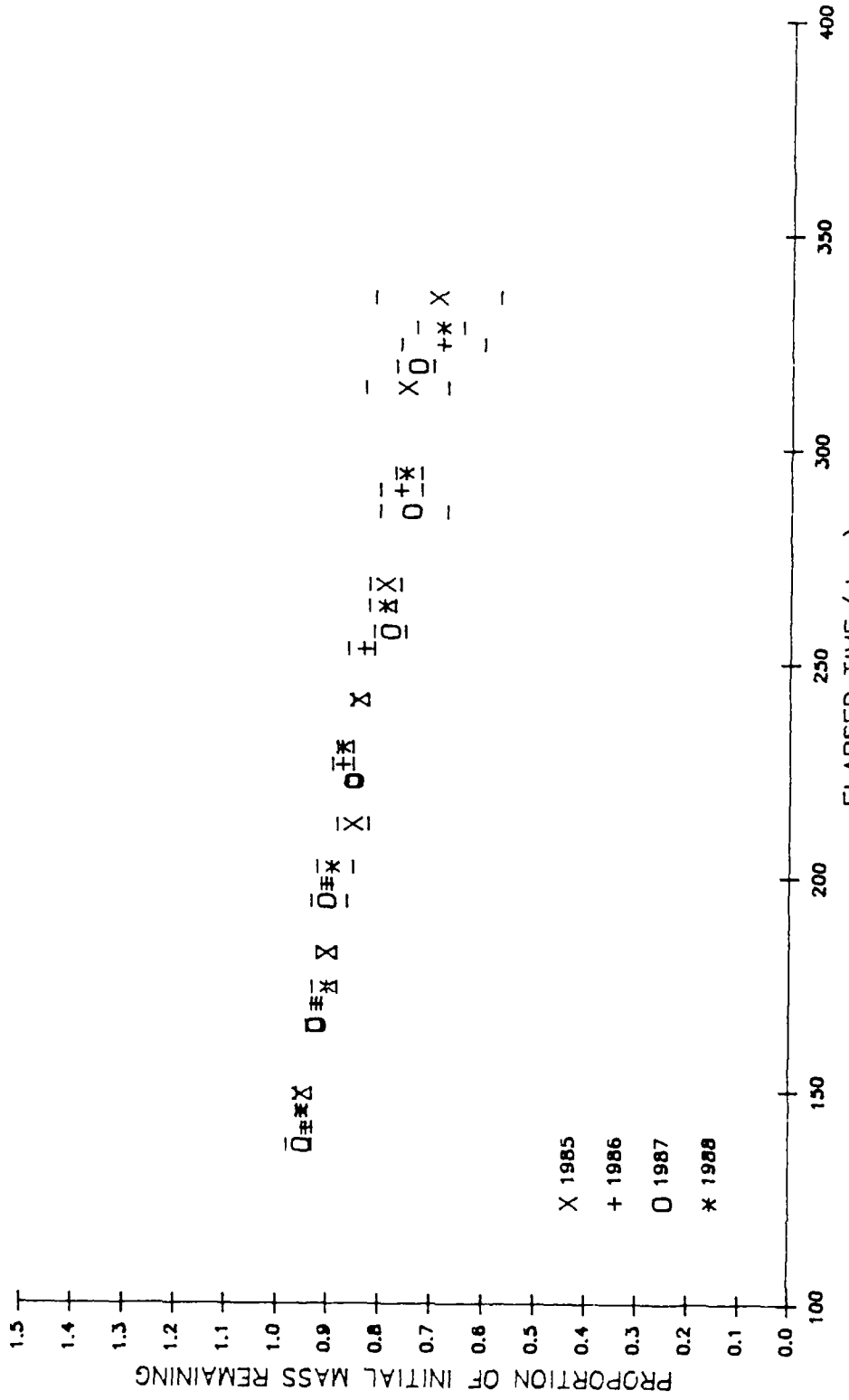

FIGURE 26. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit plantation during the four consecutive annual experiments completed to date.

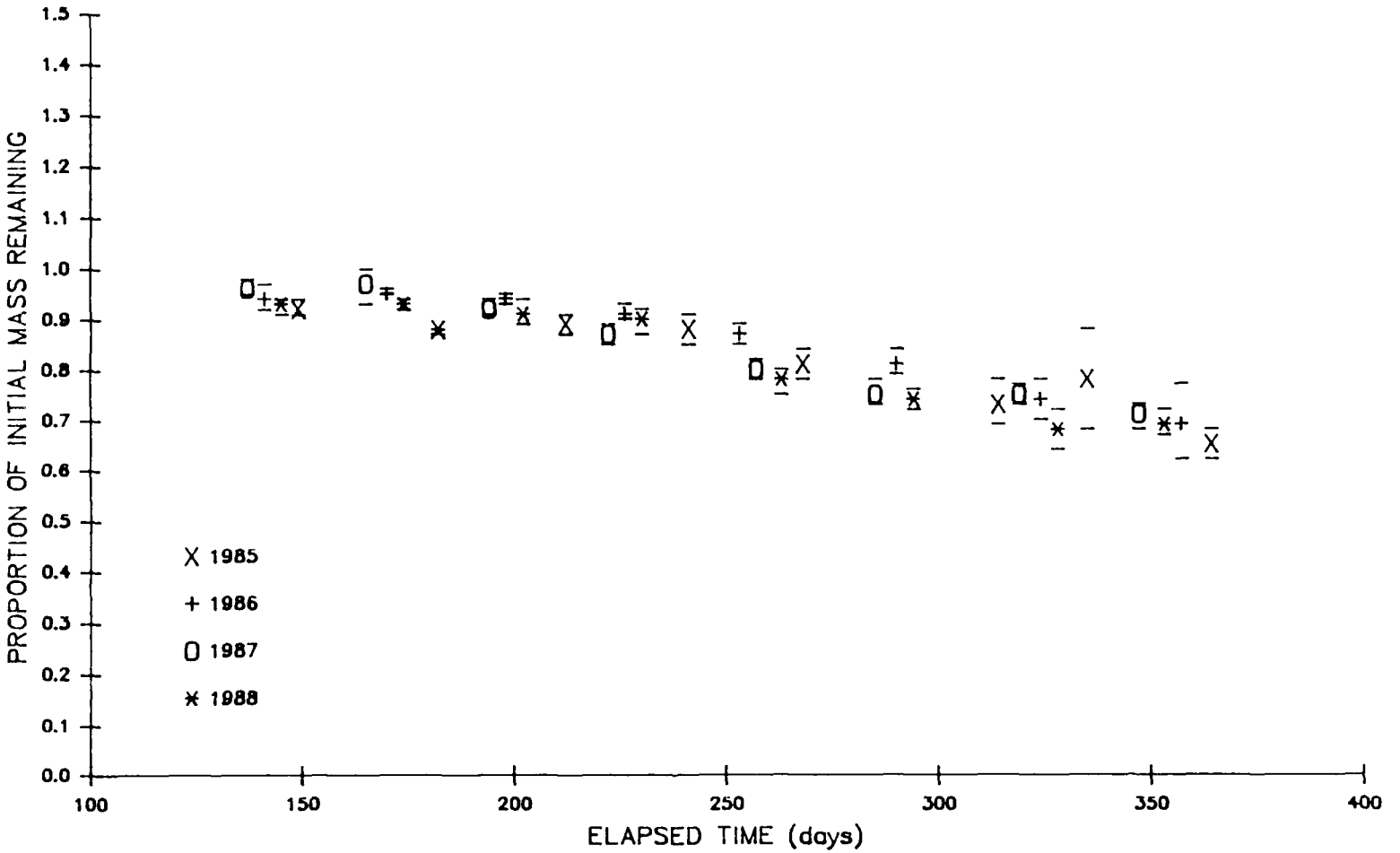

FIGURE 27. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments completed to date.

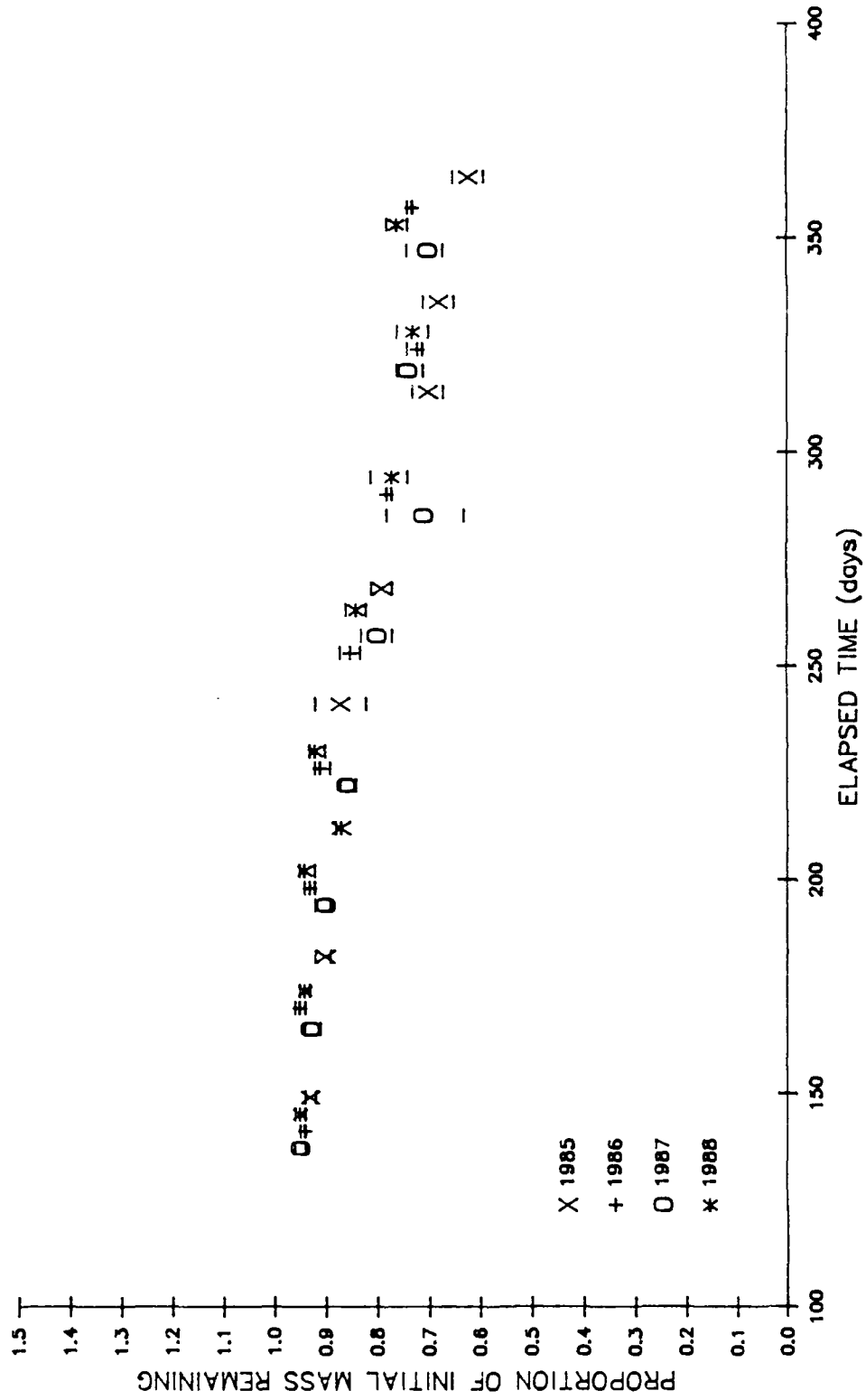

FIGURE 28. Proportion (X) of initial dry matter mass remaining for bulk oak leaf samples retrieved from the control unit hardwood stand during the four consecutive annual experiments completed to date.

Table 36. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk maple leaf samples in the three plantation subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	6.97		218.41	0.0000	0.83
Year	3		1.96	224.77	0.0000	
Month	6		4.86	279.02	0.0000	
Plantation	2		0.10	18.04	0.0001	
Error	487	1.41				
Corrected Total	498	8.38				

Table 37. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 36.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	7
1985	0.83	0.005	1.18	1985						
1986	0.98	0.005	1.00	1986				*		
1987	0.99	0.005	0.99	1987				*		
1988	0.91	0.005	1.08	1988				*	*	*
Month					1	2	3	4	5	6
May	1.08	0.006	1.09	May						
June	1.02	0.006	1.15	June	*					
July	0.98	0.006	1.20	July	*	*				
August	0.93	0.006	1.26	Aug	*	*	*			
September	0.87	0.006	1.35	Sept	*	*	*	*		
October	0.82	0.006	1.43	Oct	*	*	*	*	*	
November	0.79	0.006	1.49	Nov	*	*	*	*	*	
Plantation								G	A	
Ground	0.91	0.004	0.86	Ground						
Antenna	0.92	0.004	0.85	Antenna						
Control	0.95	0.004	0.83	Control				*	*	

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

Table 38. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk maple leaf samples in the two hardwood stand subunits, by year, sampling date, and subunit, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	4.71		263.18	0.0000	0.89
Year	3		1.98	405.35	0.0000	
Month	7		2.69	236.32	0.0000	
Hardwood Stand	1		0.02	9.62	0.0021	
Error	371	0.60				
Corrected Total	382	5.31				

Table 39. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 38.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5	6	7	
1985	0.89	0.004	0.88	1985							
1986	1.06	0.004	0.74	1986				*			
1987	1.06	0.004	0.74	1987				*			
1988	0.96	0.004	0.82	1988				*	*	*	
Month					1	2	3	4	5	6	7
May	1.11	0.006	1.06	May							
June	1.07	0.006	1.10	June	*						
July	1.07	0.006	1.10	July	*						
August	1.02	0.006	1.15	Aug	*	*	*				
September	0.97	0.006	1.21	Sept	*	*	*	*			
October	0.92	0.006	1.28	Oct	*	*	*	*	*		
November	0.90	0.006	1.31	Nov	*	*	*	*	*	*	
December	0.87	0.006	1.35	Dec	*	*	*	*	*	*	
Hardwood Stand								A			
Antenna	0.99	0.003	0.59	Antenna							
Control	1.00	0.003	0.59	Control				*			

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

and hardwood stand subunits alike, 1985 samples decomposed fastest; 1986 and 1987 samples decomposed slowest. Significant monthly progress occurred in the plantation subunits, except in October. Significant monthly progress occurred in the hardwood stands, except during June and November. Detectable differences were very low, below 1.5 percent for yearly, monthly and subunit mean values.

Figures 29 and 30 present comparisons of monthly progress in dry matter mass loss during the 1987-88 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Corresponding data for the 1986-87, 1985-86, and 1984-85 studies, respectively, were presented as Figures 41-43 in the Annual Report 1987. The bulk maple data tend to be slightly more variable than the bulk pine and bulk oak data. The similarity in bulk maple leaf decomposition among the plantation and hardwood stand subunits is encouraging.

Figure 31 presents monthly progress in dry matter mass loss during the 1984-85, 1985-86, 1986-87, and 1987-88 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 32 through 35 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the greater variability in bulk maple sample decomposition than that observed for pine or oak is clearly depicted in these figures. The significantly faster decomposition during 1985 than during any subsequent year in both the plantation and hardwood stand subunits is readily apparent.

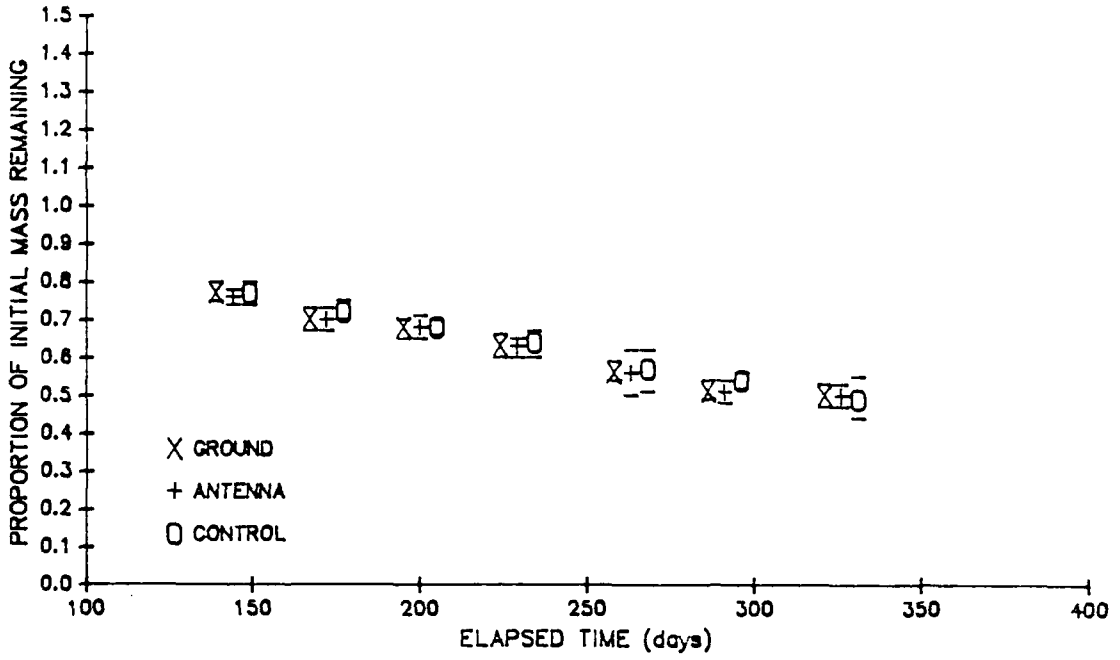

FIGURE 29. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the three plantation subunits during the 1987–1988 experiment.

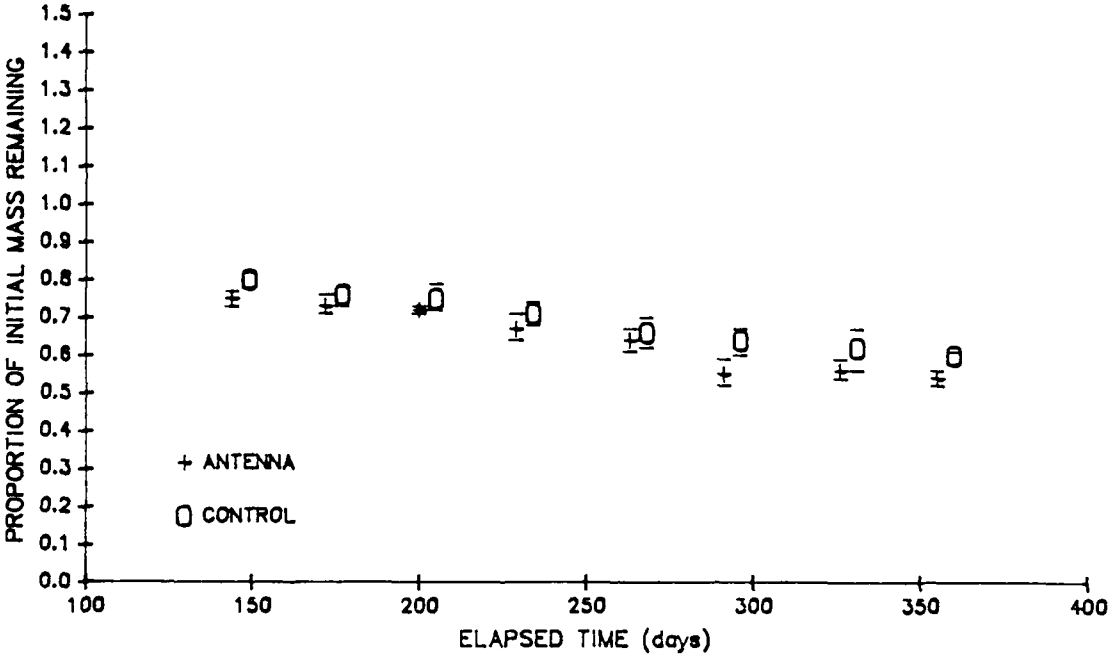

FIGURE 30. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1987–1988 experiment.

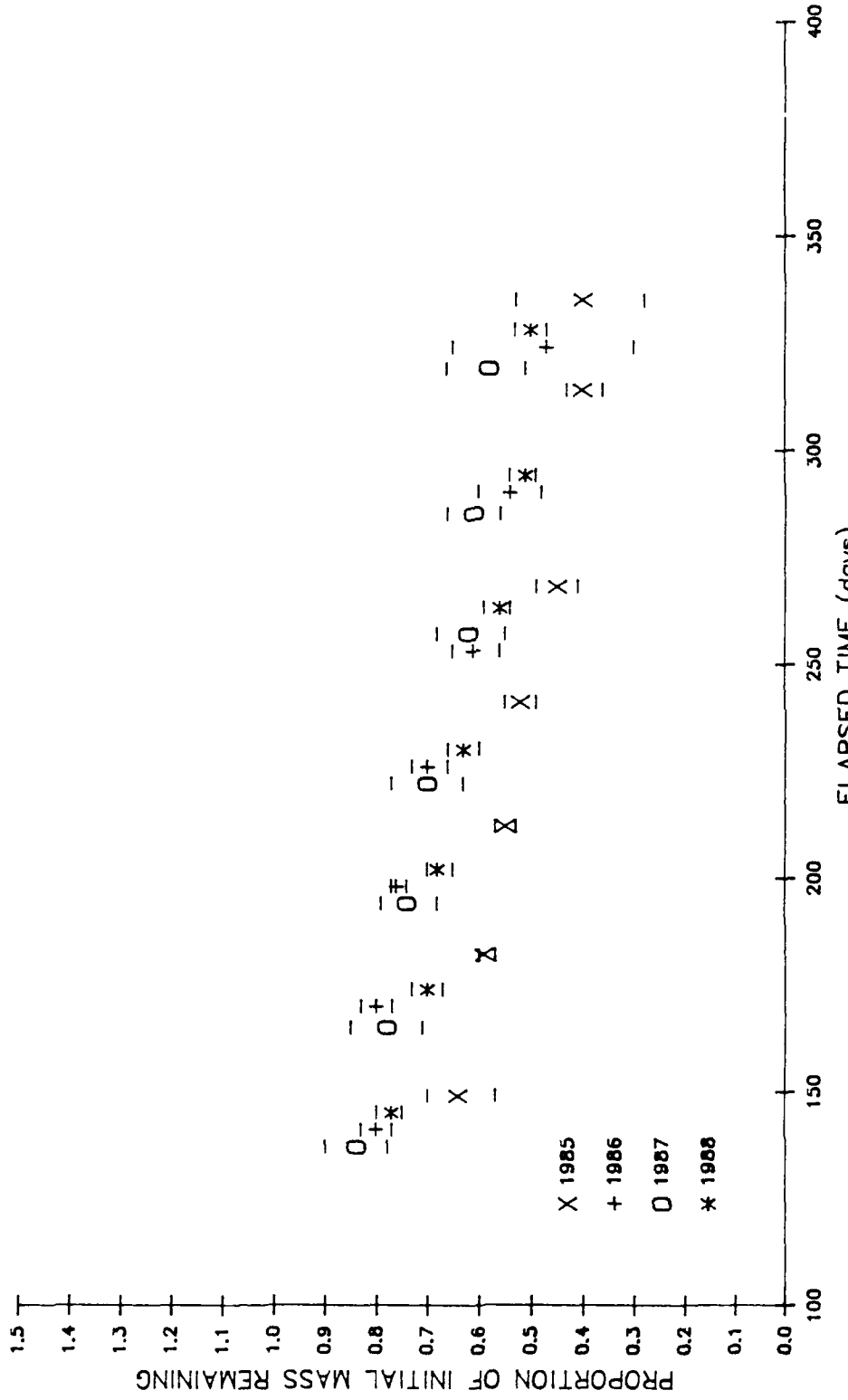

FIGURE 31. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the ground unit plantation during the four consecutive annual experiments completed to date.

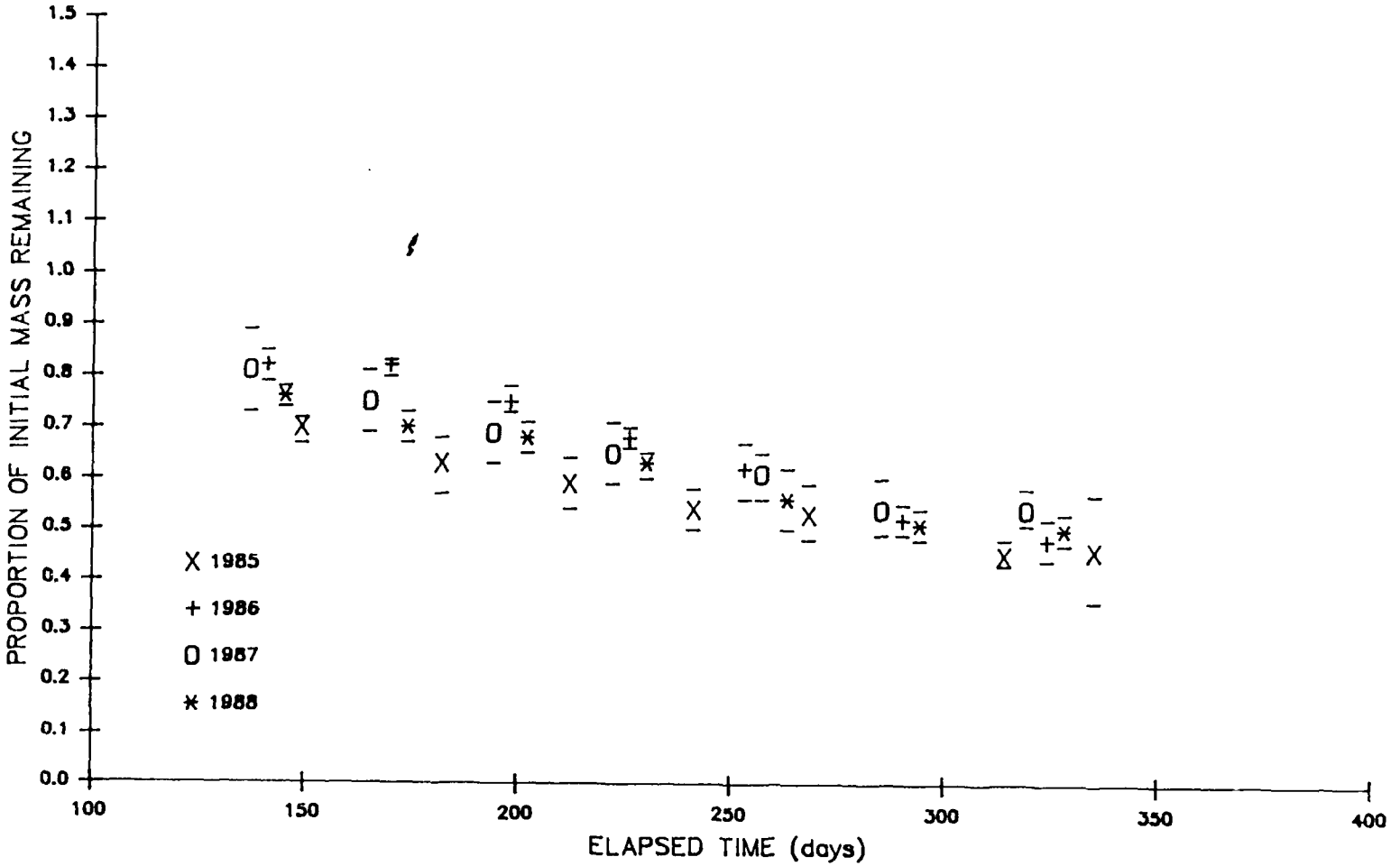

FIGURE 32. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit plantation during the four consecutive annual experiments completed to date.

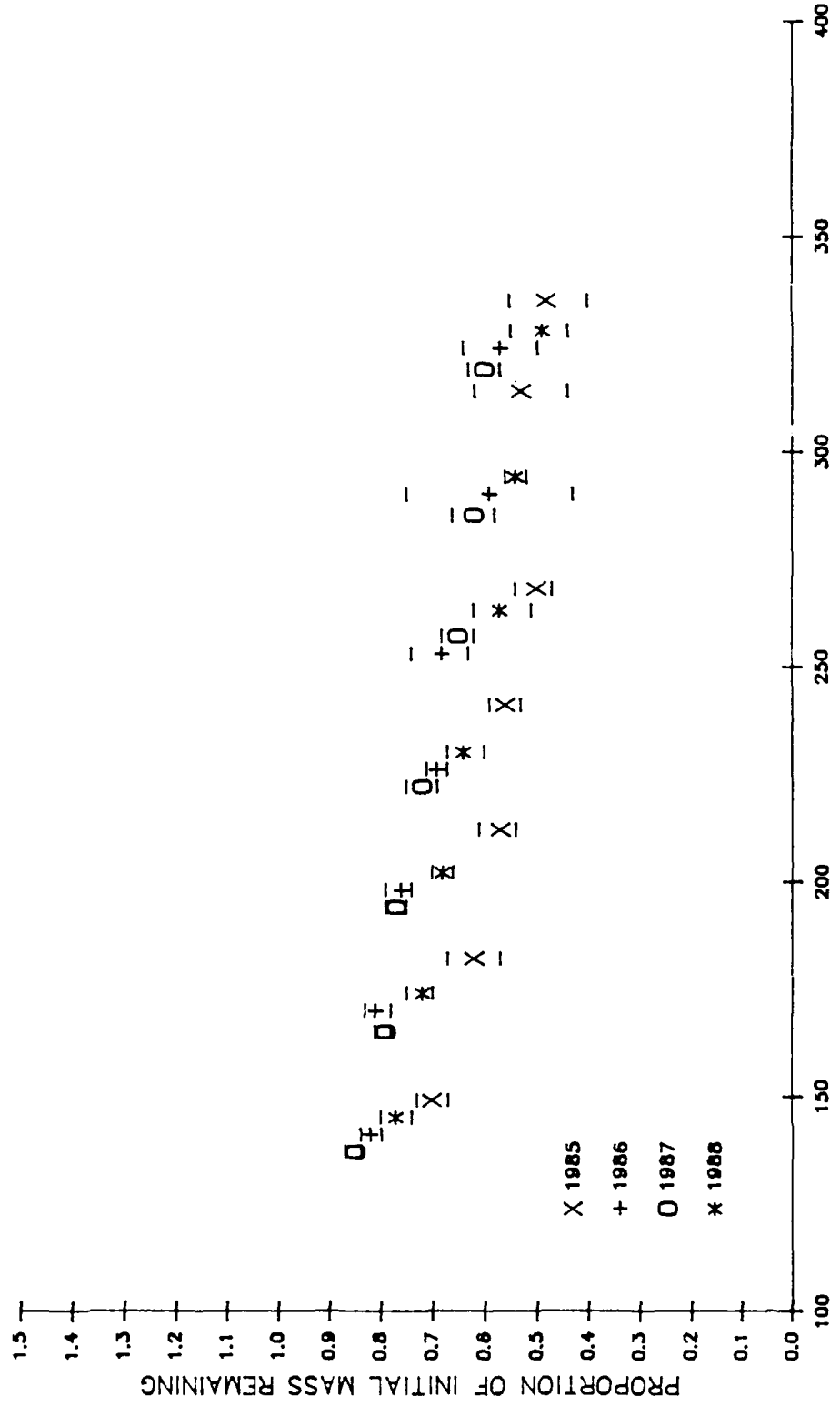

FIGURE 33. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit plantation during the four consecutive annual experiments completed to date.

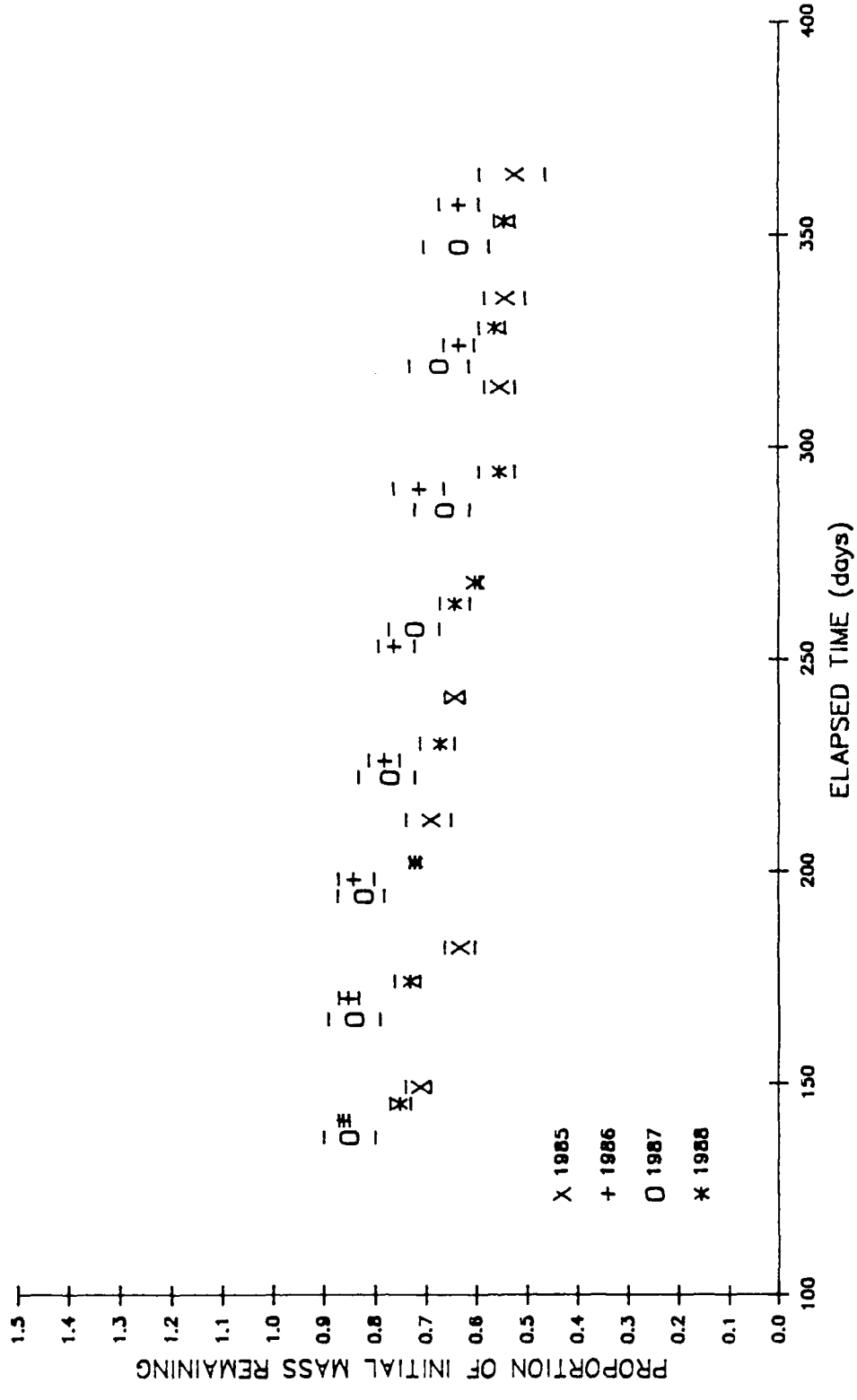

FIGURE 34. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the antenna unit hardwood stand during the four consecutive annual experiments completed to date.

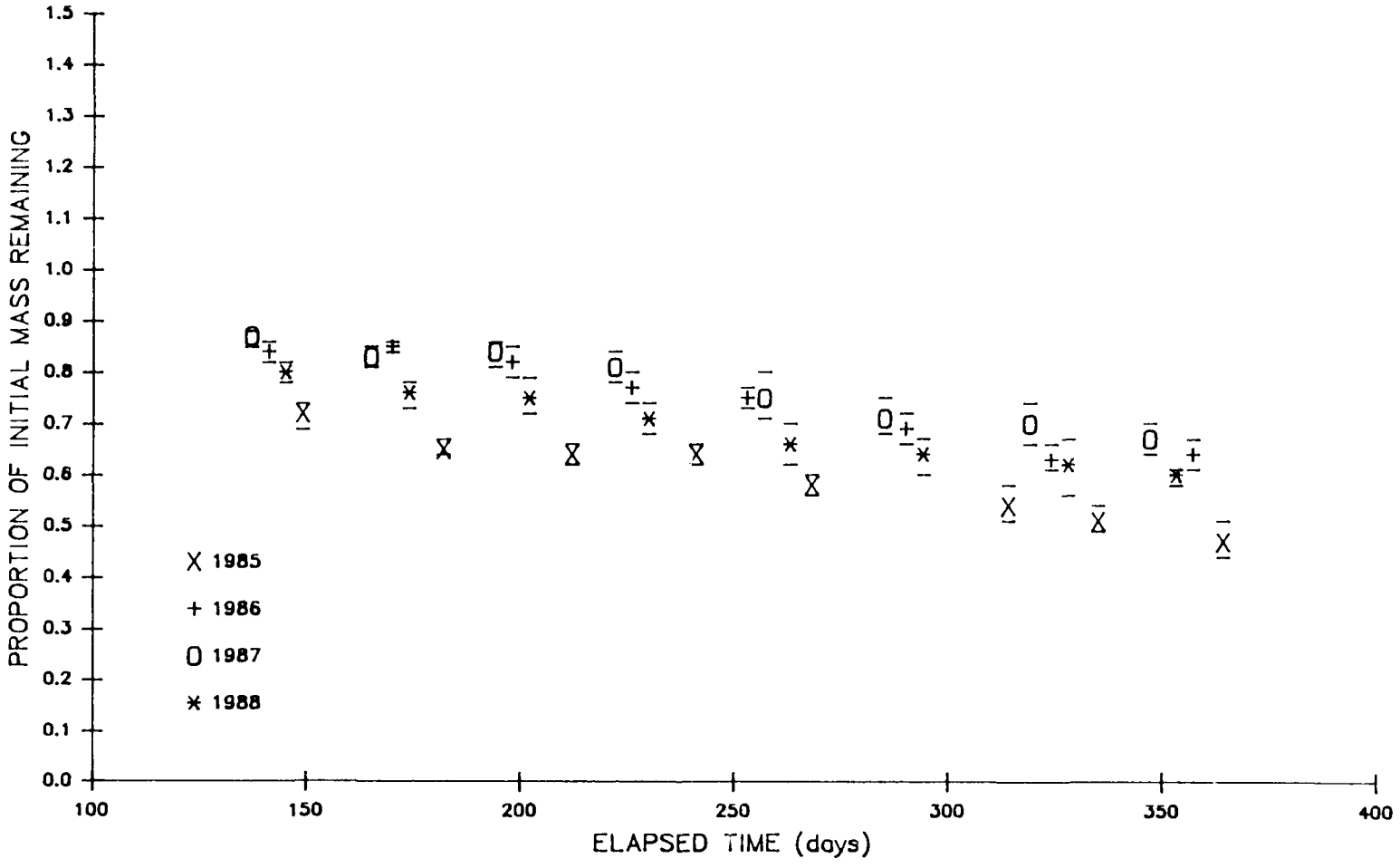

FIGURE 35. Proportion (X) of initial dry matter mass remaining for bulk maple leaf samples retrieved from the control unit hardwood stand during the four consecutive annual experiments completed to date.

ANOVA Results - Summary

The following outline summarizes the results of ANOVA on transformed dry matter mass loss data.

I. Subunits

A. Plantations
1. Pine
a. Individual fascicles decomposed faster in the ground and control plantations than in the antenna plantation.
b. Bulk samples also decomposed faster in the ground and control plantations than in the antenna plantation.
2. Oak
a. No differences among plantations were detected.
b. Bulk samples decomposed faster in the ground and antenna plantations than in the control plantation.
3. Maple
a. Bulk samples decomposed faster in the ground and antenna plantations than in the control plantation.

B. Hardwood Stands
1. Pine
a. Individual fascicles decomposed fastest in the control hardwood stand.
b. With bulk samples, no differences were detected.
2. Oak
a. For individual leaves, no differences were detected.
b. With bulk samples, no differences were detected.
3. Maple
a. Bulk samples decomposed fastest in the antenna hardwood stand.

II. Years

A. Plantations
1. Pine
a. Individual fascicles decomposed fastest in 1987 and 1988, and slowest in 1985.
b. Bulk samples decomposed fastest in 1985, and slowest in 1987 and 1988.
2. Oak
a. Individual leaves decomposed fastest in 1987 and 1988, and slowest in 1986.
b. Bulk samples decomposed fastest in 1985 and 1988, and slowest in 1986 and 1987.
3. Maple
a. Bulk samples decomposed fastest in 1985, and slowest in 1986 and 1987.

B. Hardwood Stands
   1. Pine
      a. Individual fascicles decomposed fastest in 1985, and slowest in 1986 and 1988.
      b. Bulk samples decomposed fastest in 1985, and slowest in 1988.
   2. Oak
      a. Individual leaves decomposed faster in 1985, 1987, and 1988 than in 1986.
      b. Bulk samples decomposed fastest in 1985, and slowest in 1986.
   3. Maple
      a. Bulk samples decomposed fastest in 1985, and slowest in 1986 and 1987.

From the above, and among the three study plantations, it appears that pine decomposition proceeds fastest under conditions prevailing at the ground and control plantations. Bulk oak and maple samples decomposed fastest in the ground and antenna plantations, whereas no differences among plantations were detected using individual oak leaves.

Comparing the two hardwood stands, individual pine fascicle decomposition was faster in the control hardwood stand, whereas bulk maple samples decomposed fastest in the antenna hardwood stand. No differences were detected using individual oak leaves or bulk samples of pine or oak.

It seems clear that the 1984-85 study incurred the best weather conditions to date for decomposition of all three litter species. Nevertheless, modification of the sample unit design for individual oak leaves and pine fascicles between the 1985-86 and 1986-87 studies has resulted in faster decomposition of those samples in the plantations since the modification was effected.

Oak and maple samples decomposed relatively slowly in 1986, both in the plantations and hardwood stands. Pine samples, except for individual fascicles in the plantations, decomposed relatively slower in 1988.

The differences between litter species described above suggest that different sets of covariates may be needed for each species, in order to explain differences in decomposition rate among sites and years.

Covariate Selection for Preliminary ANACOV

Prerequisites for including a variable in our covariate analyses are 1) significant correlation ($p \leq 0.05$) with transformed mass loss data, 2) a reasonable likelihood that the variable can eventually be shown to be independent of ELF field influence, and 3) a reasonable hypothetical relationship between mass loss and the potential covariate. Covariate selection and analysis of the four-year data sets has progressed much farther at present for bulk litter samples than for individual leaf samples.

The only covariates tested so far with the four-year sets of individual leaf data are 1) the percent nitrogen (STDPCN) and phosphorus (STDPCP) contents of the "standard" subsamples taken from each year's parent litter collections, 2) the densities (DENSITY) of the individual oak leaves used, and 3) combinations of these three variables. Because each year's parent litter collections are distributed to all sites, STDPCN and STDPCP can only help to explain differences among years. DENSITY can help to explain differences among sites as well as among years. Although the annual parent collections representing each litter species are made at the same location each year, all three of these variables help to characterize each year's substrate material, and thus help explain any differences in substrate quality between annual collections. Weather and other variables will be added to the analysis in the very near future.

In addition to "standard" nitrogen and phosphorus contents, weather variables have already been included in the analysis of the four-year bulk sample data sets. The weather variables considered in correlation analyses included measures of air and soil temperatures, precipitation totals and event frequencies, and soil moisture levels. Soil measures were obtained for both 5 and 10 cm depths. The weather variables selected based on the results of correlation analysis followed by ANACOV are 1) the seasonal running totals of air (ATDDRT) and soil (ST5DDRT; 5 cm depth) temperature degree days (4.4°C basis), and 2) the frequency of days with precipitation events delivering at least 0.01 (PR.01RT) or 0.10 (PR.1RT) inches of water.

A limited number of variables reflecting biotic differences between the study sites have also been tested in ANACOV models of bulk sample decomposition. In the hardwood stands, the 1987 species distributions of overstory stocking, expressed both as number of stems per hectare and basal area per hectare by species, were considered, as were the 1987 species distributions of foliar litterfall mass. In the plantations, the species distributions of stumps (density and stocking) representing the previous overstory stand were considered. Inasmuch as these variables represent a single point in time (1987), they had the potential to help explain differences among sites but not among years. The variables selected based on the results of correlation analysis followed by ANACOV included 1) the proportions of foliar litterfall contributed by red maple (LPRM) or quaking aspen (LPQA), and 2) the number of aspen stumps (NCA)

and the basal area of maple stumps (BAM) in the plantations. Because each of these covariates varies among the three contiguous plots comprising each individual plantation and hardwood stand subunit, as well as among the subunits themselves, there is reason to hope that they can be shown to be statistically independent of the ELF field exposures and/or intensities. Also, any variable with values which could not have changed since exposure to ELF fields began must be independent of ELF (i.e., could not possibly be affected by ELF fields). Examples of this kind of covariate include numbers of aspen stumps and basal area of maple stumps in the plantations. Since these covariates measure stand conditions prior to ELF exposure, independence is assured. If, however, as we suspect, the number of aspen stumps (NOA) and/or the basal area of maple stumps (BAM) should prove to be surrogates for the shading (or other) effect of aspen or maple sprouts on decomposition, then these covariates might effectively mask an effect of ELF fields on the sprouting capacity or rate of sprout growth of aspen and/or maple. For this reason, data on the extent of sprouting is being gathered and automated for consideration as covariates.

To summarize, the following variables have been used in one or more ANACOV model presented in this report:

STDPCN - the percent nitrogen content of each year's parent litter collection for each species

STDPCP - the percent phosphorus content of each year's parent litter collection for each species

DENSITY - a measure of the densities (g/cm^2) of individual oak leaves

ATDDRT - the running total, on each plot and for each year, of air temperature degree days (30 cm above ground level; 4.4°C basis)

ST5DDRT - the running total, on each plot and for each year, of soil temperature degree days (5 cm below ground level; 4.4°C basis)

PR.01RT - the running total, on each site and for each year, of days with rainfall totalling at least 0.01 inch.

PR.1RT - the running total, on each site and for each year, of days with rainfall totalling at least 0.1 inch.

BAM - the basal area per hectare (m^2/ha) of maple stumps in each plantation plot

NOA - the number of aspen stumps per hectare in each plantation plot

LPQA - the proportion of total 1987 foliar litterfall contributed by quaking aspen

LPRM - the proportion of total 1987 foliar litterfall contributed by red maple

Eventually, site x year interactions, using the covariates which could have been affected by ELF as the dependent variable, will be used to test covariates for ELF independence. We also anticipate being able to interpolate ELF field intensities at the individual litter envelope locations for evaluation as treatments, along with ELF field exposure duration and frequencies of antenna use.

ANACOV Results - Individual Fascicle/Leaf Samples

For individual pine needle fascicles and oak leaves, preliminary ANACOVs included STDPCN, STDPCP, and DENSITY (for oak leaves only) as covariates, both separately and in all combinations. The ANACOVs presented below were selected because they provide insight for explanation of significant differences detected by the 3-way ANOVAs discussed above. Additional ANACOVs including weather and other covariates will be conducted in the near future.

Individual Pine Fascicles

Nitrogen content of the parent litter collections explained all differences among years in the hardwood stands ($p = 0.8059$). Table 40 presents the ANACOV table for detection of significant differences in individual pine fascicle dry matter mass loss for the hardwood stand subunits. However, nitrogen and/or phosphorus content of the parent litter collections failed to explain all differences among years in the plantations. Use of STDPCN as the sole covariate with the plantation data only reduced the value of the F statistic for years from 38.12 to 34.24. It is not possible to determine whether or not any additional differences between years were explained by these ANACOVs, beyond the one explained by ANOVA (1987/1988), because adjusted means, standard errors, and multiple comparisons are not reported by SAS. For this reason, it is also not possible to calculate measures of detectable difference for this ANACOV. This occurs because there is only one estimate of parent litter nutrients for each year, and therefore perfect colinearity exists between the covariate (STDPCN) and one of the degrees of freedom associated with years. This can be seen by comparing Table 40 with Table 22. In Table 22, 3 degrees of freedom are associated with the Type III (partial) sum of squares for years. However, in Table 40, only 2 degrees of freedom are associated with the Type III sum of squares, and 0 degrees of freedom are associated with the covariate. The lost degree of freedom results from this perfect colinearity. When SAS detects this perfect colinearity, no

Table 40. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual pine needles** in the two **hardwood stand** subunits, using one covariate, **STDPCN**, the percent nitrogen content of each year's parent litter collection.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	16.89		725.18	0.0000	0.84
Year	2		0.00	0.22	0.8059	
Month	7		15.93	1075.08	0.0000	
Hardwood Stand	1		0.04	19.50	0.0001	
STDPCN	0		0.00	.	.	
Error	1563	3.31				
Corrected Total	1574	20.20				

estimates of adjusted means or standard errors are computed, and therefore no multiple comparisons are made.

Consideration of weather and other variables as covariates is underway. Last year we reported that ANACOVs using ATDDRT or PR.01RT as sole covariates explained differences in decomposition rate for individual pine fascicles among plantations (Annual Report 1987, Tables 46 and 48, and 50 and 52). Use of PR.01RT also explained the difference between the two hardwood stands, but not without raising detectable differences to an unacceptable level (Annual Report 1987, Tables 51 and 53).

Individual Oak Leaves

Use of leaf DENSITY as the sole covariate (Tables 41 and 42) explained the differences among the three plantations ($p = 0.3216$) more completely than the results of ANOVA ($p = 0.1146$), while continuing to provide very low detectable differences (mostly less than 1 percent). All comparisons among years, however, in the plantations were significant. This ANACOV also indicates that monthly progress in decomposition was made in the plantations. Tables 43 and 44 provide the ANACOV table and relevant statistics for use of DENSITY as the sole covariate in the hardwood stands. DENSITY also improved the explanation of hardwood stand differences obtained with ANOVA ($p = 0.5964$ vs. 0.1355). In addition, use of DENSITY also explained the difference detected by ANOVA between 1985 and 1988. Monthly progress from May through October was also made in the hardwood stands. Again, detectable differences were nearly all well below 1 percent.

Consideration of weather and other variables as potential covariates is underway. Last year we reported that no differences in decomposition were detected among years in the hardwood stands (Annual Report 1987, Tables 59 and 61), using PR.01RT as the sole covariate. The corresponding ANACOV for the plantations, however, found all comparisons among years to be significant (Annual Report 1987, Tables 58 and 60).

Table 41. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual oak** leaves in the three **plantation** subunits, using one covariate, **DENSITY**, initial leaf density (gm/cm^2).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	56.75		502.27	0.0000	0.73
Year	3		8.51	301.28	0.0000	
Month	6		43.89	776.97	0.0000	
Plantation	2		0.02	1.14	0.3216	
DENSITY	1		3.33	353.79	0.0001	
Error	2208	20.79				
Corrected Total	2220	77.54				

Table 42. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 41.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year							5	6	7	
1985	1.11	0.004	0.71	1985						
1986	1.14	0.004	0.69	1986			*			
1987	1.02	0.005	0.96	1987			*	*		
1988	0.99	0.004	0.79	1988			*	*	*	
Month					1	2	3	4	5	6
May	1.29	0.005	0.76	May						
June	1.20	0.005	0.82	June	*					
July	1.14	0.005	0.86	July	*	*				
August	1.06	0.005	0.92	Aug	*	*	*			
September	0.98	0.005	1.00	Sept	*	*	*	*		
October	0.92	0.005	1.07	Oct	*	*	*	*	*	
November	0.87	0.005	1.13	Nov	*	*	*	*	*	*
Plantation							G	A		
Ground	1.06	0.004	0.74	Ground						
Antenna	1.06	0.004	0.74	Antenna						
Control	1.07	0.004	0.73	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 43. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **individual oak** leaves in the two **hardwood stand** subunits, using one covariate, **DENSITY**, initial leaf density (gm/cm^2).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	29.46		470.53	0.0000	0.77
Year	3		0.75	47.78	0.0001	
Month	7		27.37	749.62	0.0000	
Hardwood Stand	1		0.00	0.28	0.5964	
DENSITY	1		1.17	224.08	0.0001	
Error	1682	8.77				
Corrected Total	1694	38.23				

Table 44. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 43.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5		6		7
1985	1.12	0.003	0.52	1985							
1986	1.17	0.003	0.50	1986				*			
1987	1.14	0.004	0.69	1987				*		*	
1988	1.12	0.004	0.70	1988						*	*
Month					1	2	3	4	5	6	7
May	1.31	0.005	0.75	May							
June	1.27	0.005	0.77	June	*						
July	1.25	0.005	0.78	July	*	*					
August	1.19	0.005	0.82	Aug	*	*	*				
September	1.11	0.005	0.88	Sept	*	*	*	*			
October	1.03	0.005	0.95	Oct	*	*	*	*	*		
November	0.97	0.005	1.01	Nov	*	*	*	*	*	*	
December	0.97	0.005	1.01	Dec	*	*	*	*	*	*	
Plantation								G		A	
Antenna	1.14	0.002	0.34	Antenna							
Control	1.14	0.002	0.34	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

ANACOV Results - Bulk Leaf Litter Samples

Bulk Pine Needle Litter

For the plantation data, Table 45 presents the ANACOV table for detection of significant differences in dry matter mass loss, using PR.1RT as the sole covariate. Table 46 presents the associated comparative statistics for the treatments corresponding to the plantations. Tables 47 and 48 present the analogous information for the plantation ANACOV using both PR.1RT and ST5DDRT as covariates.

Among the plantation subunits, ANACOV using PR.1RT as the sole covariate explained ($p = 0.1817$) the important difference between 1985 and 1988 detected by ANOVA. The apparent similarity between the ground and control plantations was also somewhat increased over that indicated by ANOVA ($p = 0.8047$ vs. 0.6872). ANACOV using ST5DDRT as well as PR.1RT as covariates further increased the p values for comparisons between 1985 and 1988 ($p = 0.3788$), and between the ground and control plantations ($p = 0.8663$). This ANACOV also explained many monthly differences in decomposition which were detected by ANOVA. Detectable differences remained low, below 1 percent for years and sites, and below 5 percent for months.

For the hardwood stand data, Table 49 presents the ANACOV table for detection of significant differences in dry matter mass loss, using PR.01RT as the sole covariate. Table 50 presents the associated comparative statistics for the treatments corresponding to the hardwood stands. Table 51 presents the ANACOV table for detection of significant differences in dry matter mass loss, using LPRM as the sole covariate, and Table 52 presents the associated comparative statistics for the treatments. Tables 53 and 54 present the analogous information for the plantation ANACOV using both PR.01RT and LPRM as covariates.

Between the two hardwood stands, ANACOV using PR.01RT as the sole covariate explained more satisfactorily than did ANOVA the similarity between 1986 and 1987 ($p = 0.9235$ vs. 0.0718). On the other hand, ANACOV using LPRM as the sole covariate greatly increased the apparent similarity between the two hardwood stands ($p = 0.5679$ vs. 0.0597). Used together as covariates, PR.01RT and LPRM did a better job of explaining the two hardwood stands ($p = 0.6509$) than did either covariate alone, and the 1986 vs. 1987 comparison remained as well explained as when PR.01RT was used as the only covariate. This ANACOV indicated that monthly progress was made from May through September. Detectable differences remained low, approximately 1 percent for years and sites, and below 3.5 percent for months.

Bulk Oak Leaf Litter

For the plantation data, Table 55 presents the ANACOV table for detection of significant differences in dry matter mass loss, using ATDDRT and PR.1RT as covariates. Table 56 presents the

Table 45. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, using one covariate, **PR.1RT**, the running total of days with precipitation events exceeding 0.1 inch in total.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	4.50		328.65	0.0000	0.89
Year	3		0.13	37.42	0.0001	
Month	6		0.09	13.30	0.0001	
Plantation	2		0.04	18.42	0.0001	
PR.1RT	1		0.02	18.18	0.0001	
Error	491	0.56				
Corrected Total	503	5.06				

Table 46. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 45.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	7
1985	1.14	0.005	0.86	1985						
1986	1.13	0.004	0.69	1986						
1987	1.18	0.003	0.50	1987				*	*	
1988	1.15	0.004	0.68	1988					*	*
Month					1	2	3	4	5	6
May	1.23	0.011	1.75	May						
June	1.20	0.009	1.47	June	*					
July	1.19	0.006	0.99	July	*	*				
August	1.16	0.004	0.68	Aug	*	*	*			
September	1.11	0.005	0.88	Sept	*	*	*	*		
October	1.08	0.010	1.81	Oct	*	*	*	*	*	
November	1.07	0.013	2.38	Nov	*	*	*	*	*	
Plantation								G		A
Ground	1.14	0.003	0.52	Ground						
Antenna	1.16	0.003	0.51	Antenna				*		
Control	1.14	0.003	0.52	Control						*

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 47. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the three **plantation** subunits, using two covariates: running totals of 1) soil temperature degree days (**ST5DDRT**; 5 cm depth, 4.4°C basis), and 2) number of days with precipitation events exceeding .01 inch in total (**PR.01RT**).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	4.50		304.56	0.0000	0.89
Year	3		0.13	38.26	0.0001	
Month	7		0.02	3.66	0.0014	
Plantations	1		0.04	19.73	0.0001	
ST5DDRT	1		0.02	2.61	0.1070	
PR.01RT	1		0.00	19.26	0.0001	
Error	490	0.56				
Corrected Total	503	5.06				

Table 48. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 47.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	7
1985	1.14	0.005	0.86	1985						
1986	1.13	0.005	0.87	1986						
1987	1.18	0.004	0.66	1987				*	*	
1988	1.15	0.004	0.68	1988					*	*
Month					1	2	3	4	5	6
May	1.18	0.028	4.65	May						
June	1.17	0.021	3.52	June	*					
July	1.17	0.012	2.01	July						
August	1.16	0.004	0.68	Aug						
September	1.13	0.013	2.25	Sept				*		
October	1.11	0.021	3.71	Oct			*	*		
November	1.11	0.025	4.41	Nov				*		
Hardwood Stand								G		A
Ground	1.14	0.003	0.52	Ground						
Antenna	1.16	0.003	0.51	Antenna				*		
Control	1.14	0.003	0.52	Control						*

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 49. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, using one covariate, **PR.01RT**, the running total of days with precipitation events exceeding 0.01 inch in total.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	4.22		339.44	0.0000	0.92
Year	3		0.12	37.56	0.0001	
Month	7		0.18	25.06	0.0001	
Hardwood Stands	1		0.00	3.26	0.0719	
PR.01RT	1		0.00	1.16	0.2826	
Error	357	0.37				
Corrected Total	369	4.59				

Table 50. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 49.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5		6		7	
1985	1.10	0.006	1.07	1985						
1986	1.14	0.006	1.03	1986	*					
1987	1.14	0.005	0.86	1987	*					
1988	1.16	0.005	0.84	1988	*		*		*	
Month					1	2	3	4	5	6 7
May	1.27	0.017	2.62	May						
June	1.23	0.013	2.07	June	*					
July	1.21	0.009	1.46	July	*	*				
August	1.17	0.006	1.01	Aug	*	*	*			
September	1.09	0.005	0.90	Sept	*	*	*	*		
October	1.05	0.010	1.87	Oct	*	*	*	*	*	
November	1.03	0.016	3.04	Nov	*	*	*	*	*	
December	1.04	0.018	3.39	Dec	*	*	*	*	*	
Plantation							A			
Antenna	1.13	0.002	0.35	Antenna						
Control	1.14	0.002	0.34	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 51. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, using one covariate, **LPRM**, the proportion by weight of 1987 total foliar litterfall represented by red maple.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	4.41		351.96	0.0000	0.92
Year	3		0.23	74.85	0.0001	
Month	7		4.17	570.67	0.0000	
Hardwood Stands	1		0.00	0.33	0.5679	
LPRM	1		0.00	0.01	0.9053	
Error	369	0.38				
Corrected Total	381	4.79				

Table 52. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 51.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year							5		6		7
1985	1.09	0.003	0.54	1985							
1986	1.15	0.003	0.51	1986			*				
1987	1.14	0.003	0.52	1987			*				
1988	1.16	0.003	0.51	1988			*		*		*
Month					1	2	3	4	5	6	7
May	1.29	0.005	0.76	May							
June	1.25	0.005	0.78	June	*						
July	1.22	0.005	0.80	July	*	*					
August	1.18	0.005	0.83	Aug	*	*	*				
September	1.08	0.005	0.91	Sept	*	*	*	*			
October	1.04	0.005	0.94	Oct	*	*	*	*	*		
November	1.02	0.005	0.96	Nov	*	*	*	*	*	*	
December	1.01		0.97	Dec	*	*	*	*	*	*	
Hardwood Stand							A				
Antenna	1.13	0.007	1.21	Antenna							
Control	1.14	0.007	1.20	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 53. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk pine** needle samples in the two **hardwood stand** subunits, using two covariates: 1) **LPRM**, the proportion by weight of 1987 total foliar litterfall represented by red maple, and 2) **PR.01RT**, the running total of days with precipitation events exceeding 0.01 inch in total.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	4.22		312.45	0.0000	0.92
Year	3		0.12	37.45	0.0001	
Month	7		0.18	24.99	0.0001	
Hardwood Stands	1		0.00	0.21	0.6509	
LPRM	1		0.00	0.00	0.9896	
PR.01RT	1		0.00	1.15	0.2833	
Error	356	0.37				
Corrected Total	369	4.59				

Table 54. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 53.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5	6	7	
1985	1.10	0.006	1.07	1985							
1986	1.14	0.006	1.03	1986				*			
1987	1.14	0.005	0.86	1987				*			
1988	1.16	0.005	0.84	1988				*	*	*	
Month					1	2	3	4	5	6	7
May	1.27	0.017	2.62	May							
June	1.23	0.013	2.07	June	*						
July	1.21	0.009	1.46	July	*	*					
August	1.17	0.006	1.01	Aug	*	*	*				
September	1.09	0.005	0.90	Sept	*	*	*	*			
October	1.05	0.010	1.87	Oct	*	*	*	*	*		
November	1.03	0.016	3.04	Nov	*	*	*	*	*		
December	1.04	0.018	3.39	Dec	*	*	*	*	*		
Plantation							A				
Antenna	1.13	0.007	1.21	Antenna							
Control	1.14	0.007	1.20	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 55. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** subunits, using two covariates: 1) **ATDDRT**, the running total of air temperature degree days (4.4°C basis), and 2) **PR.1RT**, the running total of days with precipitation events exceeding 0.1 inch in total.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	6.35		172.06	0.0000	0.82
Year	3		0.07	8.06	0.0001	
Month	6		0.02	1.04	0.3999	
Plantation	2		0.06	10.34	0.0001	
ATDDRT	1		0.00	0.90	0.3440	
PR.1RT	1		0.03	12.23	0.0005	
Error	487	1.38				
Corrected Total	500	7.73				

Table 56. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, means, based on the model analyzed in Table 55.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]	
Year					5 6 7
1985	1.15	0.009	1.53	1985	
1986	1.15	0.007	1.19	1986	
1987	1.17	0.006	1.01	1987	
1988	1.13	0.006	1.04	1988	* *
Month					1 2 3 4 5 6
May	1.05	0.038	7.09	May	
June	1.07	0.029	5.31	June	
July	1.12	0.016	2.80	July	
August	1.17	0.007	1.17	Aug	
September	1.20	0.019	3.10	Sept	
October	1.21	0.030	4.86	Oct	
November	1.21	0.036	5.83	Nov	
Plantation					G A
Ground	1.14	0.004	0.69	Ground	
Antenna	1.14	0.004	0.69	Antenna	
Control	1.17	0.005	0.84	Control	* *

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

associated comparative statistics for the treatments corresponding to the plantations. Tables 57 and 58 present the analogous information for the plantation ANACOV using NOA as well as ATDDRT and PR.1RT as covariates.

Among the plantation subunits, ANACOV using ATDDRT and PR.1RT as covariates explained the differences between 1985 and 1987 ($p = 0.1155$) and between 1985 and 1986 ($p = 0.9378$), which were detected by ANOVA. This ANACOV also modestly improved the explanation obtained with ANOVA of differences between 1985 and 1988 ($p = 0.1150$ vs. 0.0803) and between 1986 and 1987 ($p = 0.1208$ vs. 0.1001). The apparent similarity between the ground and antenna plantations was maintained. ANACOV using NOA as well as ATDDRT and PR.1RT as covariates maintained the explanations of yearly comparisons obtained with the first ANACOV, while explaining all differences among plantations ($p = 0.2933$). This ANACOV also explained all monthly differences in decomposition which were detected by ANOVA. Detectable differences remained low (well below 2 percent) for years and sites, and modest (below 7 percent) for months.

For the hardwood stand data, Table 59 presents the ANACOV table for detection of significant differences in dry matter mass loss, using PR.1RT as the sole covariate. Table 60 presents the associated comparative statistics for the treatments corresponding to the hardwood stands. Table 61 presents the ANACOV table for detection of significant differences in dry matter mass loss, using ST5DDRT as well as PR.1RT as covariates, and Table 62 presents the associated comparative statistics for the treatments.

Between the hardwood stands, ANACOV using PR.1RT as the sole covariate explained the important differences detected by ANOVA between 1986 and 1987 ($p = 0.6067$) and, especially, between 1985 and 1988 ($p = 0.8277$). Explanation of the difference between hardwood stands was maintained ($p = 0.3330$). When ST5DDRT is added to the ANACOV with PR.1RT, the explanation of hardwood stand differences is greatly improved ($p = 0.9242$). The explanation of the difference between 1985 and 1988 is slightly less convincing ($p = 0.3507$) with this ANACOV, though the explanation of the difference between 1986 and 1987 is improved ($p = 0.7894$). The model including ST5DDRT explained many more differences in monthly decomposition progress than did the model with PR.1RT alone, undoubtedly in part due to larger detectable differences for early and late months. Nevertheless, detectable differences among months were low (between 1 and 4 percent) for the simpler model, and modest (between 1 and 6 percent) for the second model. Detectable differences for both models were very low for differences between hardwood stands (well below 1 percent) and years (well below 2 percent).

Bulk Maple Leaf Litter

For the plantation data, Table 63 presents the ANACOV table for detection of significant differences in dry matter mass loss, using PR.1RT as the sole covariate. Table 64 presents the

Table 57. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the three **plantation** subunits, using three covariates: 1) **ATDDRT**, running total of air temperature degree days (4.4°C basis), 2) **PR.1RT**, the running total of days with precipitation events exceeding 0.1 inch in total, and 3) **NOA**, the number of aspen stumps on each plantation plot.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	6.36		162.00	0.0000	0.82
Year	3		0.07	8.08	0.0001	
Month	6		0.02	1.03	0.4049	
Plantation	2		0.01	1.23	0.2933	
ATDDRT	1		0.00	1.02	0.3129	
PR.1RT	1		0.03	12.29	0.0005	
NOA	1		0.02	6.41	0.0117	
Error	486	1.36				
Corrected Total	500	7.73				

Table 58. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 57.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5	6	7	
1985	1.15	0.009	1.53	1985							
1986	1.15	0.007	1.19	1986							
1987	1.17	0.006	1.01	1987							
1988	1.13	0.006	1.04	1988					*	*	
Month					1	2	3	4	5	6	7
May	1.22	0.037	5.94	May							
June	1.19	0.029	4.78	June							
July	1.18	0.016	2.66	July							
August	1.16	0.007	1.18	Aug							
September	1.13	0.018	3.12	Sept							
October	1.10	0.030	5.35	Oct							
November	1.09	0.036	6.47	Nov							
Hardwood Stand									G	A	
Ground	1.15	0.005	0.85	Ground							
Antenna	1.15	0.005	0.85	Antenna							
Control	1.16	0.006	1.01	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 59. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, using one covariate, **PR.1RT**, the running total of days with precipitation events exceeding 0.1 inch in total .

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	6.33		243.88	0.0000	0.89
Year	3		0.05	7.78	0.0001	
Month	7		0.14	9.22	0.0001	
Hardwood Stand	1		0.00	0.94	0.3330	
PR.1RT	1		0.02	11.04	0.0010	
Error	358	0.77				
Corrected Total	370	7.10				

Table 60. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 59.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5	6	7	
1985	1.15	0.009	1.53	1985							
1986	1.18	0.007	1.16	1986				*			
1987	1.18	0.006	1.00	1987				*			
1988	1.16	0.006	1.01	1988					*	*	
Month					1	2	3	4	5	6	7
May	1.27	0.019	2.93	May							
June	1.26	0.016	2.49	June							
July	1.24	0.012	1.90	July	*						
August	1.22	0.008	1.29	Aug	*	*	*				
September	1.14	0.007	1.20	Sept	*	*	*	*			
October	1.09	0.013	2.34	Oct	*	*	*	*	*		
November	1.08	0.018	3.27	Nov	*	*	*	*	*		
December	1.04	0.021	3.96	Dec	*	*	*	*	*	*	*
Hardwood Stand								A			
Antenna	1.17	0.003	0.50	Antenna							
Control	1.17	0.004	0.50	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 61. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk oak** leaf samples in the two **hardwood stand** subunits, using two covariates: 1) **PR.1RT**, the running total of days with precipitation events exceeding 0.1 inch in total, and 2) **ST5DDRT**, the running total of soil temperature degree days (5 cm depth; 4.4°C basis).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	6.34		229.14	0.0000	0.89
Year	3		0.06	9.92	0.0001	
Month	7		0.11	7.26	0.0001	
Hardwood Stand	1		0.00	0.01	0.9242	
PR.1RT	1		0.02	10.83	0.0011	
ST5DDRT	1		0.01	6.58	0.0107	
Error	357	0.76				
Corrected Total	370	7.10				

Table 62. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 61.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5	6	7	
1985	1.15	0.009	1.53	1985							
1986	1.19	0.007	1.15	1986				*			
1987	1.18	0.006	1.00	1987				*			
1988	1.16	0.006	1.01	1988					*	*	
Month					1	2	3	4	5	6	7
May	1.20	0.033	5.39	May							
June	1.21	0.027	4.37	June							
July	1.21	0.017	2.75	July							
August	1.21	0.008	1.30	Aug							
September	1.17	0.013	2.18	Sept				*			
October	1.13	0.022	3.82	Oct			*	*	*		
November	1.13	0.028	4.86	Nov				*			
December	1.09	0.029	5.21	Dec	*	*	*	*	*	*	
Plantation							A				
Antenna	1.17	0.003	0.50	Antenna							
Control	1.17	0.004	0.67	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 63. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** subunits, using one covariate, **PR.1RT**, the running total of days with precipitation events exceeding 0.1 inch in total.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	6.97		200.06	0.0000	0.83
Year	3		1.35	155.15	0.0001	
Month	6		0.33	19.05	0.0001	
Plantation	2		0.10	16.88	0.0001	
PR.1RT	1		0.00	0.52	0.4707	
Error	486	1.41				
Corrected Total	498	8.38				

Table 64. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 63.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	7
1985	0.82	0.009	2.15	1985						
1986	0.98	0.007	1.40	1986				*		
1987	0.98	0.005	1.00	1987				*		
1988	0.92	0.006	1.28	1988				*	*	*
Month					1	2	3	4	5	6
May	1.09	0.018	3.24	May						
June	1.03	0.014	2.66	June	*					
July	0.98	0.010	2.00	July	*	*				
August	0.93	0.007	1.48	Aug	*	*	*			
September	0.86	0.009	2.05	Sept	*	*	*	*		
October	0.80	0.015	3.67	Oct	*	*	*	*	*	
November	0.78	0.021	5.28	Nov	*	*	*	*	*	*
Plantation							G		A	
Ground	0.91	0.004	0.86	Ground						
Antenna	0.92	0.004	0.85	Antenna						
Control	0.95	0.004	0.83	Control			*		*	

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

associated comparative statistics for the treatments corresponding to the plantations. Tables 65 and 66 present the analogous information for the plantation ANACOV using BAM as well as PR.1RT as covariates.

Among the plantation subunits, use of PR.1RT as the sole covariate provided better explanation than did ANOVA of the difference between 1986 and 1987 ($p = 0.7371$ vs. 0.2090). However, only the difference between the ground and antenna plantations was explained ($p = 0.6179$). Adding BAM as a covariate with PR.1RT resulted in very effective explanation of all differences among plantations ($p = 0.9832$). Both models indicated monthly progress in decomposition. Detectable differences were well below 2.5 percent for years, less than 1.5 percent for plantations, and between 1.5 and 5.5 percent for months.

For the hardwood stand data, Table 67 presents the ANACOV table for detection of significant differences in dry matter mass loss, using PR.1RT as the sole covariate. Table 68 presents the associated comparative statistics for the treatments corresponding to the hardwood stands. Table 69 presents the ANACOV table for detection of significant differences in dry matter mass loss, using LPQA as the sole covariate, and Table 70 presents the associated comparative statistics for the treatments. Tables 71 and 72 present analogous information for the ANACOV using both PR.1RT and LPQA as covariates.

Between hardwood stands, use of PR.1RT as the sole covariate provided better explanation than did ANOVA for the difference between 1986 and 1987 ($p = 0.7636$ vs. 0.1856). Use of LPQA as the sole covariate explained the difference detected by ANOVA between the two hardwood stands ($p = 0.8551$). The ANACOV including both PR.1RT and LPQA as covariates provided good explanations of both the differences between hardwood stands ($p = 0.7777$) and between 1986 and 1987 ($p = 0.6536$). With all three models, decomposition progressed monthly, except in June. Detectable differences were well below 2 percent for years, well below 1 percent for hardwood stands, and nearly all below 4 percent for months.

Table 65. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the three **plantation** subunits, using two covariates: 1) **PR.1RT**, the running total of days with precipitation events exceeding 0.1 inch in total, and 2) **BAM**, the basal area of maple stumps on each plantation plot.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	7.01		190.28	0.0000	0.84
Year	3		1.35	159.03	0.0001	
Month	6		0.33	19.53	0.0001	
Plantation	1		0.00	0.02	0.9832	
PR.1RT	1		0.00	0.53	0.4688	
BAM	1		0.04	13.11	0.0003	
Error	485	1.37				
Corrected Total	498	8.38				

Table 66. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 65.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	7
1985	0.82	0.009	2.15	1985						
1986	0.98	0.007	1.40	1986				*		
1987	0.98	0.005	1.00	1987				*		
1988	0.92	0.006	1.28	1988				*	*	*
Month					1	2	3	4	5	6
May	1.09	0.017	3.06	May						
June	1.03	0.014	2.66	June	*					
July	0.98	0.010	2.00	July	*	*				
August	0.93	0.007	1.48	Aug	*	*	*			
September	0.86	0.009	2.05	Sept	*	*	*	*		
October	0.81	0.015	3.63	Oct	*	*	*	*	*	
November	0.78	0.021	5.28	Nov	*	*	*	*	*	*
Hardwood Stand							A		C	
Ground	0.93	0.005	1.05	Ground						
Antenna	0.93	0.005	1.05	Antenna						
Control	0.93	0.007	1.48	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 67. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, using one covariate, **PR.1RT**, the running total of the number of days with precipitation events exceeding 0.1 inch in total.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	4.47		226.08	0.0000	0.88
Year	3		1.55	312.49	0.0000	
Month	7		0.12	10.30	0.0001	
Hardwood Stand	1		0.01	6.37	0.0120	
PR.1RT	1		0.00	0.60	0.4390	
Error	358	0.59				
Corrected Total	370	5.06				

Table 68. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 67.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5		6		7
1985	0.89	0.007	1.54	1985							
1986	1.06	0.006	1.11	1986				*			
1987	1.06	0.005	0.92	1987				*			
1988	0.96	0.005	1.02	1988				*		*		*
Month					1	2	3	4	5	6	7
May	1.12	0.017	2.97	May							
June	1.08	0.014	2.54	June	*						
July	1.08	0.010	1.81	July	*						
August	1.03	0.007	1.33	Aug	*	*	*				
September	0.97	0.007	1.41	Sept	*	*	*	*			
October	0.91	0.011	2.37	Oct	*	*	*	*	*		
November	0.88	0.016	3.56	Nov	*	*	*	*	*	*	
December	0.86	0.018	4.10	Dec	*	*	*	*	*	*	*
Hardwood Stand							A				
Antenna	0.99	0.003	0.59	Antenna							
Control	1.00	0.003	0.59	Control			*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 69. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, using one covariate, **LPQA**, the proportion of total 1987 foliar litter provided by quaking aspen.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	4.72		245.89	0.0000	0.89
Year	3		1.98	412.57	0.0000	
Month	7		2.69	240.05	0.0000	
Hardwood Stand	1		0.00	0.03	0.8551	
LPQA	1		0.01	7.21	0.0076	
Error	370	0.59				
Corrected Total	382	5.31				

Table 70. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 69.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year								5		6	7
1985	0.89	0.004	0.88	1985							
1986	1.06	0.004	0.74	1986				*			
1987	1.06	0.004	0.74	1987				*			
1988	0.96	0.004	0.82	1988				*		*	*
Month					1	2	3	4	5	6	7
May	1.11	0.006	1.06	May							
June	1.07	0.006	1.10	June	*						
July	1.07	0.006	1.10	July	*						
August	1.02	0.006	1.15	Aug	*	*	*				
September	0.97	0.006	1.21	Sept	*	*	*	*			
October	0.92	0.006	1.28	Oct	*	*	*	*	*		
November	0.90	0.006	1.31	Nov	*	*	*	*	*	*	
December	0.87	0.006	1.35	Dec	*	*	*	*	*	*	*
Hardwood Stand								A			
Antenna	0.99	0.004	0.79	Antenna							
Control	0.99	0.004	0.79	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 71. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from **bulk maple** leaf samples in the two **hardwood stand** subunits, using two covariates: 1) **PR.1RT**, the running total of the number of days with precipitation events exceeding 0.1 inch in total, and 2) **LPQA**, the proportion of total 1987 foliar litter provided by quaking aspen.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	4.48		212.56	0.0000	0.89
Year	3		1.55	317.90	0.0000	
Month	7		0.12	10.51	0.0001	
Hardwood Stand	1		0.00	0.20	0.6536	
PR.1RT	1		0.00	0.65	0 4192	
LPQA	1		0.01	6.75	0.0098	
Error	357	0.58				
Corrected Total	370	5.06				

Table 72. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 71.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6	7			
1985	0.89	0.007	1.54	1985						
1986	1.06	0.006	1.11	1986	*					
1987	1.06	0.005	0.92	1987	*					
1988	0.96	0.005	1.02	1988	*	*	*			
Month					1	2	3	4	5	6	7
May	1.12	0.017	2.97	May							
June	1.09	0.014	2.52	June	*						
July	1.08	0.010	1.81	July	*						
August	1.03	0.007	1.33	Aug	*	*	*				
September	0.97	0.006	1.21	Sept	*	*	*	*			
October	0.91	0.011	2.37	Oct	*	*	*	*	*		
November	0.88	0.016	3.56	Nov	*	*	*	*	*	*	
December	0.86	0.018	4.10	Dec	*	*	*	*	*	*	*
Plantation							A				
Antenna	0.99	0.004	0.79	Antenna							
Control	0.99	0.004	0.79	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

ANACOV Results - Summary

The following outline summarizes the most useful results obtained to date from ANACOV on transformed dry matter mass loss data.

I. Subunits

A. Plantations

1. Pine
   a. Using individual fascicles, ANOVA explained the difference between the ground and control plantations. Decomposition was apparently faster on both of these sites than on the antenna site. Use of weather covariates may provide better explanations.
   b. Using bulk samples, with PR.1RT and ST5DDRT as covariates, the difference between the ground and control plantations was well explained. After accounting for the covariates, decomposition was apparently faster on these sites than in the antenna plantation.

2. Oak
   a. Using individual leaves, with DENSITY as the only covariate, no differences were detected.
   b. Using bulk samples, with ATDDRT, PR.1RT, and NOA as covariates, no differences were detected.

3. Maple
   a. Using bulk samples, with PR.1RT and BAM as covariates, no differences were detected.

B. Hardwood Stands

1. Pine
   a. Using individual fascicles, ANOVA failed to explain the difference between the hardwood stands. Decomposition apparently proceeds faster at the control site than at the antenna site. Weather and/or other covariates may explain this difference.
   b. Using bulk samples, with PR.01RT and LPRM as covariates, no difference was detected.

2. Oak
   a. Using individual leaves, with DENSITY as the only covariate, no difference was found.
   b. Using bulk samples, with PR.1RT and ST5DDRT as covariates, no differences were detected.

3. Maple
   a. Using bulk samples, with PR.1RT and LPQA as covariates, do difference was detected.

II. Years

A. Plantations

1. Pine
   a. Using individual fascicles, ANOVA found that fascicles decomposed fastest in 1987 and 1988, and slowest in 1985. Use of weather covariates may provide better explanation.
   b. Using bulk samples, with PR.01RT and ST5DDRT as covariates, comparisons of 1985 with 1988 and 1986 were not significant. Accounting for the covariates, decomposition was apparently fastest in 1985 and 1986, and slowest in 1987.

2. Oak
   a. Using individual leaves, ANOVA failed to explain any differences among years. Use of weather covariates may well explain at least some of these differences.
   b. Using bulk samples, with ATDDRT, PR.1RT, and NOA as covariates, comparisons of 1985 with 1986 through 1988 were not significant, and the difference between 1986 and 1987 was also explained. After accounting for the covariates, decomposition was faster in 1988 than in either 1986 or 1987.

3. Maple
   a. Using bulk samples, with PR.1RT and BAM as covariates, the difference between 1986 and 1987 was explained. Accounting for the covariates, decomposition apparently proceeded fastest in 1985 and slowest in 1986 and 1987.

B. Hardwood Stands

1. Pine
   a. Using individual fascicles, with STDPCN as a covariate explained all differences among years.
   b. Using bulk samples, with PR.01RT and LPRM as covariates, the difference between 1986 and 1987 was explained. After accounting for the covariates, decomposition was apparently fastest in 1985, and slowest in 1988.

2. Oak
   a. Using individual leaves, with DENSITY as the only covariate, the important difference between 1985 and 1988 was explained. After accounting for the covariates, decomposition was apparently fastest in 1985 and 1988, and slowest in 1986.

b. Using bulk samples, with PR.1RT and ST5DDRT as covariates, the differences between 1985 and 1988, and between 1986 and 1987, were explained. After accounting for the covariates, decomposition was apparently faster in 1985 and 1988 than in 1986 and 1987.

3. Maple
   a. Using bulk samples, with PR.1RT and LPQA as covariates, The difference between 1986 and 1987 was explained. Accounting for the covariates, decomposition apparently proceeded fastest in 1985 and slowest in 1986 and 1987.

ANACOV has been very effective both for explaining differences detected by ANOVA and for strengthening the explanations of other differences already provided by ANOVA. One of the major goals of our ANACOV analysis is to explain differences detected by ANOVA between the two hardwood stands and between the three plantations in the decomposition rates of individual pine and oak leaves as well as of bulk samples of all three litter species. With ANACOV, differences between the two hardwood stands have been explained for all sample types except for individual pine fascicles. Our ANACOV analysis of the individual pine fascicles has just begun, though, and weather and stand-related variables remain to be taken into consideration. Individual leaf density explained the difference between hardwood stands for individual oak leaves. Unfortunately, density values are not available for bulk samples of either oak or maple, and would be difficult to obtain. ST5DDRT substantially improved on the explanation provided by ANOVA for bulk oak samples, whereas the character of the litterfall appeared to reflect factors which influenced the decomposition of bulk pine and maple samples. The species composition of foliar litterfall might be expected to affect litter decomposition through its influence on forest floor properties and decomposer communities.

Nearly all differences in decomposition rate between the three plantations have been explained using ANACOV. The only remaining unexplained differences are the comparisons between the antenna and control plantations, and between the ground and antenna plantations, for individual pine fascicles and bulk pine samples. Again, weather and other variables have yet to be examined with the four-year individual fascicle data set, and last year we reported that all differences detected with individual pine fascicles among the three plantations could be explained by using either ATDDRT or PR.01RT in separate ANACOVs (Annual Report 1987, page 143). DENSITY was again effective as a covariate for individual oak leaves. With bulk pine samples, PR.1RT was the covariate which most improved the explanation of plantation differences provided by ANOVA. Interestingly, NOA and BAM were the covariates most useful for explaining the differences detected among the plantations in bulk oak and maple

decomposition, respectively. Both covariates had a positive influence on mass loss in the plantations. Both aspen and red maple sprout aggressively, aspen from the roots and maple from the stump root collar. It seems likely that aspen sprouts may be shading litter samples, thereby protecting them from dessication and permitting more effective use of available precipitation and degree days for decomposition. Perhaps maple stump basal area relates to maple decomposition in a similar manner.

STDPCN explained all differences in individual pine fascicle decomposition among years for the hardwood stands. It is not surprising to find that substrate quality may be influencing decomposition rate. It does seem surprising to find that STDPCN is not also useful as a covariate with bulk pine litter samples, or with the other litter species. DENSITY, however, was useful for explaining the difference between 1985 and 1988 in decomposition of individual oak leaves. Examination of weather variables may explain other differences among years for individual oak leaves. Last year, we reported that all differences among years for individual oak leaves in the hardwood stands were explained using PR.01RT as the sole covariate (Annual Report 1987, page 145). PR.01RT has been the most useful covariate so far for explaining differences in bulk pine sample decomposition among years, but only the difference between 1986 and 1987 has been explained. PR.1RT has been the most useful covariate so far for explaining differences in bulk oak sample decomposition among years, having explained the differences between 1985 and 1988, and between 1986 and 1987. PR.1RT was also useful for improving the explanation provided by ANOVA of the difference between 1986 and 1987 in bulk maple decomposition.

Neither STDPCN nor STDPCP explained any differences among years for any sample type in the plantations. ANOVA failed to explain any differences among years in the plantations for individual oak leaves, and explained only the difference between 1987 and 1988 for individual pine fascicles. Both PR.01RT and ST5DDRT contributed to a sound explanation of the differences between 1985 and 1988, and between 1985 and 1986, for bulk pine samples. Comparisons of 1985 with 1986 through 1988, and of 1986 with 1987, were explained for bulk oak samples, using PR.1RT and ATDDRT together as covariates. Use of PR.1RT as a covariate improved the explanation provided by ANOVA for the difference between 1986 and 1987 in bulk maple decomposition.

We anticipate that explanation of all differences in decomposition rate among years for all litter sample types is probably an unrealistic goal. This is especially likely in the plantation subunits, where relatively rapid successional vegetational changes add to and interact with yearly differences in weather patterns. We have been satisfied so far to identify covariates which explain differences between pre-ELF years (1985 and 1986) and ELF years (1987 and, especially, 1988). Of course, ELF exposure was minimal in 1987. PR.01RT and PR.1RT have been the most important covariates so far for explanation of differences in decomposition rate among years, regardless of litter species. It appears that measures of air or soil

temperature (ATDDRT or ST5DDRT) are also important in the plantations, but not in the hardwood stands. In the exposed environment of the plantations, temperature is likely to be highly related to solar radiation reaching ground level, and both of these must have a strong influence on moisture loss following precipitation events.

Nutrient Content of Bulk Standards

The random samples drawn periodically from the pine, oak, and maple parent litter collections during the course of field sample preparation are referred to as bulk standards. These samples are used to estimate the initial condition of the litter comprising the field samples. The percent nitrogen, phosphorus, potassium, calcium, magnesium and ash contents of the bulk standards from each annual study are presented in Tables 73 - 78, along with the results of multiple comparison tests based on the following ANOVAs. One-way ANOVA tables for detection of differences among years in ash, nitrogen, phosphorus, potassium, calcium, and magnesium content of the annual pine parent litter collections are presented as Tables 79 - 84, respectively. Corresponding ANOVA tables for the oak and maple parent litter collections are presented as Tables 85 - 90 and 91 - 96, respectively.

Significant differences among years were detected by ANOVA for all species/nutrient combinations. For this reason, the mean percent N, P, K, Ca and Mg contents of the parent litter collections representing each species in each annual decomposition study are being evaluated for use as covariates to help explain differences among years in decomposition rates.

Nutrient Content of Retrieved Samples

Nutrient flux involved with bulk sample decomposition for each litter species has been determined for the 1984-85, 1985-86, and 1986-87 studies. Because of resource limitations, only the samples collected in May, July, September, and November of 1987 have been chemically analyzed. Bulk samples from the 1987-88 study are being ground for chemical analysis. For statistical analysis, the N, P, K, Ca, Mg, and ash contents of retrieved litter samples are expressed either as 1) the proportion (X) of their original mass remaining at the time of sample retrieval, or 2) the percent content of the retrieved samples. X values relate remaining nutrient content to initial nutrient content of the sample; percent nutrient content is not corrected for dry matter mass loss. X values relate meaningfully to nutrient losses (or gains) during litter decomposition, but percentages should prove useful as covariates related to dry matter mass loss. X values could be used as independent variables in separate analyses of nutrient flux which would parallel the studies of dry matter mass loss reported here. We have chosen to focus on the use of litter nutrient contents as covariates. The nutrient contents of retrieved samples might prove to be useful covariates as indicators of the previous availability of nutrients to fuel dry matter mass loss. However, it may be difficult to establish statistical independence from ELF for nutrient content variables.

The following tables and figures represent the available data for the percent nutrient contents of bulk samples retrieved in the 1984-85, 1985-86, and 1986-87 studies. The nitrogen contents of pine, oak and maple samples retrieved in the 1984-85

Table 73. Percent **nitrogen** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, 1986, 1987 and 1988 field seasons

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987
Pine	1984	0.496	10	0.015				
	1985	0.429	16	0.012	*			
	1986	0.309	15	0.012	*	*		
	1987	0.367	12	0.013	*	*	*	
	1988	0.316	14	0.012	*	*		
Oak	1985	0.637	15	0.028				
	1986	0.835	17	0.026		*		
	1987	0.428	12	0.031		*	*	
	1988	0.477	14	0.029		*	*	
Maple	1985	0.537	15	0.039				
	1986	1.115	16	0.038		*		
	1987	0.494	12	0.044			*	
	1988	0.495	14	0.041			*	

a/ $\alpha = 0.05$, Tukey's H.S.D.

Table 74. Percent **phosphorus** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, 1986, 1987 and 1988 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987
Pine	1984	0.054	10	0.003				
	1985	0.037	16	0.002	*			
	1986	0.048	15	0.002		*		
	1987	0.039	12	0.002	*		*	
	1988	0.051	14	0.002		*		*
Oak	1985	0.071	15	0.004				
	1986	0.083	17	0.004				
	1987	0.107	12	0.004		*	*	
	1988	0.072	14	0.004				*
Maple	1985	0.080	15	0.005				
	1986	0.124	16	0.005		*		
	1987	0.051	12	0.005		*	*	
	1988	0.056	14	0.005		*	*	

a/ $\alpha = 0.05$, Tukey's H.S.D.

Table 75. Percent **potassium** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, 1986, 1987 and 1988 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987
Pine	1984	0.413	10	0.016				
	1985	0.083	15	0.013	*			
	1986	0.059	15	0.013	*			
	1987	0.045	12	0.014	*			
	1988	0.034	14	0.013	*			
Oak	1985	0.119	15	0.005				
	1986	0.144	17	0.005		*		
	1987	0.259	12	0.006		*	*	
	1988	0.198	14	0.006		*	*	*
Maple	1985	0.449	15	0.012				
	1986	0.212	16	0.011		*		
	1987	0.146	12	0.013		*	*	
	1988	0.372	14	0.012		*	*	*

a/ α = 0.05, Tukey's H.S.D.

Table 76. Percent **calcium** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, 1986, 1987 and 1988 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987
Pine	1984	0.592	10	0.012				
	1985	0.412	15	0.010	*			
	1986	0.350	15	0.010	*	*		
	1987	0.373	12	0.011	*			
	1988	0.484	14	0.010	*	*	*	*
Oak	1985	1.036	15	0.017				
	1986	0.984	17	0.016				
	1987	1.014	12	0.019				
	1988	0.954	14	0.018		*		
Maple	1985	0.925	15	0.027				
	1986	1.041	16	0.026		*		
	1987	0.905	12	0.030			*	
	1988	0.964	14	0.028				

a/ α = 0.05, Tukey's H.S.D.

Table 77. Percent **magnesium** content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, 1986, 1987 and 1988 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987
Pine	1984	0.111	10	0.003				
	1985	0.081	15	0.002	*			
	1986	0.083	15	0.002	*			
	1987	0.076	12	0.003	*			
	1988	0.082	14	0.003	*			
Oak	1985	0.126	15	0.002				
	1986	0.117	17	0.002		*		
	1987	0.161	12	0.002		*	*	
	1988	0.120	14	0.002				*
Maple	1985	0.137	15	0.004				
	1986	0.130	16	0.004				
	1987	0.114	12	0.005		*		
	1988	0.135	14	0.004				*

a/ α = 0.05, Tukey's H.S.D.

Table 78. Percent **ash** weight of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, 1986, 1987 and 1988 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985	1986	1987
Pine	1984	4.7	10	0.3				
	1985	3.2	15	0.3	*			
	1986	3.5	15	0.3				
	1987	3.8	12	0.3				
	1988	3.2	14	0.3	*			
Oak	1985	9.2	15	0.3				
	1986	7.9	17	0.3		*		
	1987	9.1	12	0.4				
	1988	8.4	14	0.3				
Maple	1985	10.7	15	0.4				
	1986	11.1	16	0.4				
	1987	9.6	12	0.4			*	
	1988	10.5	14	0.4				

a/ α = 0.05, Tukey's H.S.D.

Table 79. ANOVA table for detection of differences in **ash** mass among the **pine** litter parent collections used in the 1983-1984, 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	4	0.0018	0.0004	3.68	0.0095
Within Groups	62	0.0056	0.0001		
Total	66	0.0074			

Table 80. ANOVA table for detection of differences in **nitrogen** mass among the **pine** litter parent collections used in the 1983-1984, 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	4	0.3081	0.0770	36.24	0.0001
Within Groups	62	0.1020	0.0021		
Total	66	0.3323			

Table 81. ANOVA table for detection of differences in **phosphorus** mass among the **pine** litter parent collections used in the 1983-1984, 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	4	0.0031	0.0008	11.74	0.0001
Within Groups	62	0.0041	0.0001		
Total	66	0.0072			

Table 82. ANOVA table for detection of differences in **potassium** mass among the **pine** litter parent collections used in the 1983-1984, 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	4	1.0982	0.2745	110.26	0.0001
Within Groups	61	0.1519	0.0025		
Total	65	1.2501			

Table 83. ANOVA table for detection of differences in **calcium** mass among the **pine** litter parent collections used in the 1983-1984, 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	4	0.4410	0.1102	78.11	0.0001
Within Groups	61	0.0861	0.0014		
Total	65	0.5271			

Table 84. ANOVA table for detection of differences in **magnesium** mass among the **pine** litter parent collections used in the 1983-1984, 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	4	0.0082	0.0021	22.03	0.0001
Within Groups	61	0.0057	0.0001		
Total	65	0.0139			

Table 85. ANOVA table for detection of differences in **ash** mass among the **oak** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.0016	0.0005	3.72	0.0167
Within Groups	54	0.0079	0.0001		
Total	57	0.0096			

Table 86. ANOVA table for detection of differences in **nitrogen** mass among the **oak** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	1.5124	0.5041	43.06	0.0001
Within Groups	54	0.6322	0.0117		
Total	57	2.1446			

Table 87. ANOVA table for detection of differences in **phosphorus** mass among the **oak** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.0106	0.0035	15.64	0.0001
Within Groups	54	0.0122	0.0002		
Total	57	0.0227			

Table 88. ANOVA table for detection of differences in **potassium** mass among the **oak** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.1550	0.0517	121.70	0.0001
Within Groups	54	0.0229	0.0004		
Total	57	0.1780			

Table 89. ANOVA table for detection of differences in **calcium** mass among the **oak** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.0557	0.0186	4.24	0.0092
Within Groups	54	0.2365	0.0044		
Total	57	0.2922			

Table 90. ANOVA table for detection of differences in **magnesium** mass among the **oak** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.0164	0.0055	80.52	0.0001
Within Groups	54	0.0037	0.0001		
Total	57	0.0201			

Table 91. ANOVA table for detection of differences in **ash** mass among the **maple** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.0017	0.0006	2.66	0.0574
Within Groups	53	0.0113	0.0002		
Total	56	0.0130			

Table 92. ANOVA table for detection of differences in **nitrogen** mass among the **maple** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	4.2313	1.4104	60.37	0.0001
Within Groups	53	1.2382	0.0234		
Total	56	5.4695			

Table 93. ANOVA table for detection of differences in **phosphorus** mass among the **maple** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.0487	0.0162	46.21	0.0001
Within Groups	53	0.0186	0.0004		
Total	56	0.0673			

Table 94. ANOVA table for detection of differences in **potassium** mass among the **maple** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.8165	0.2722	134.30	0.0001
Within Groups	53	0.1074	0.0020		
Total	56	0.9239			

Table 95. ANOVA table for detection of differences in **calcium** mass among the **maple** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.1578	0.0526	4.92	0.0044
Within Groups	53	0.5672	0.0107		
Total	56	0.7250			

Table 96. ANOVA table for detection of differences in **magnesium** mass among the **maple** litter parent collections used in the 1984-1985, 1985-1986, 1986-1987, and 1987-1988 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	3	0.0038	0.0013	4.96	0.0042
Within Groups	53	0.0137	0.0003		
Total	56	0.0175			

study are presented in Tables 97 - 99; analogous data for phosphorus are presented in Tables 100 - 102, for potassium in Tables 103 - 105, for calcium in Tables 106 - 108, and for magnesium in Tables 109 - 111. Tables 112 - 126 present the analogous data for the 1985-86 study; Tables 127 - 141 present the analogous data for the 1986-87 study.

The nitrogen contents of the bulk pine samples retrieved in 1987 from the three plantations are compared in Figure 36; analogous data for the two hardwood stands are compared in Figure 37. Analogous comparisons for the 1985-86 and 1984-85 studies are presented as Figures 38 - 41. Corresponding comparisons among plantations and hardwood stands for the bulk oak samples retrieved in the same years are presented as Figures 42 - 47, and for the bulk maple samples in Figures 48 - 53. Comparisons of the phosphorus content of bulk samples retrieved from the plantations and hardwood stands during each annual study, and for each litter species, are presented as Figures 54 - 71. Analogous comparisons of potassium, calcium and magnesium contents are presented as Figures 72 - 89, 90 - 107, and 108 - 125, respectively.

Yearly comparisons of the nitrogen content of bulk pine samples retrieved from the ground, antenna, and control plantations, and from the antenna and control hardwood stands, are presented as Figures 126 - 130. Corresponding comparisons for bulk oak and bulk maple samples are presented as Figures 131 - 135 and Figures 136 - 140, respectively. Analogous yearly comparisons are presented as Figures 141 - 155 for phosphorus, as Figures 156 - 170 for potassium, as Figures 171 - 185 for calcium, and as Figures 186 - 200 for magnesium.

Table 97. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.47	0.03	6	0.51	0.06	13
2 June	0.49	0.02	5	0.54	0.04	7
2 July	0.54	0.04	8	0.62	0.04	6
31 July	0.52	0.04	7	0.59	0.05	9
27 August	0.60	0.03	5	0.56	0.03	5
12 October	0.72	0.08	12	0.71	0.11	17
2 November	0.37	0.30	83	0.64	0.09	14
1 December				0.68	0.09	14

Table 97. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.55	0.08	16	0.48	0.03	7
2 June	0.54	0.05	9	0.51	0.07	16
2 July	0.58	0.04	7	0.55	0.05	9
31 July	0.63	0.06	9	0.54	0.05	9
27 August	0.86	0.19	23	0.72	0.12	17
12 October	0.84	0.15	18	0.64	0.09	15
2 November	0.78	0.04	6	0.70	0.08	14
1 December				0.75	0.08	11

Table 97. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.47	0.03	8
2 June	0.49	0.04	10
2 July	0.59	0.05	9
31 July	0.52	0.04	8
27 August	0.57	0.02	5
12 October	0.77	0.07	10
2 November	0.28	0.13	48
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 98. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot: Plantation Mean	S.D.[a]	%[b]	Antenna Plot: Hardwood Stand Mean	S.D.	%
30 April	0.75	0.06	8	0.82	0.09	11
2 June	0.89	0.15	17	0.93	0.08	9
2 July	0.90	0.10	12	0.97	0.11	12
31 July	0.89	0.03	4	0.89	0.05	6
27 August	0.77	0.06	8	0.74	0.08	11
12 October	0.76	0.27	37	0.93	0.52	58
2 November	0.94	0.11	12	1.00	0.06	7
1 December				0.92	0.13	15

Table 98. (cont)

Sampling Date	Control Plot: Plantation Mean	S.D.	%	Control Plot: Hardwood Stand Mean	S.D.	%
30 April	0.76	0.09	13	0.80	0.08	11
2 June	0.79	0.06	9	0.80	0.10	13
2 July	0.88	0.06	8	0.95	0.03	3
31 July	0.94	0.06	7	0.91	0.12	14
27 August	0.83	0.04	5	0.84	0.05	6
12 October	0.94	0.40	45	1.36	0.29	22
2 November	0.94	0.10	11	0.94	0.09	10
1 December				0.91	0.08	9

Table 98. (cont)

Sampling Date	Ground Plot: Plantation Mean	S.D.	%
30 April	0.77	0.06	9
2 June	0.79	0.04	5
2 July	0.88	0.06	7
31 July	1.01	0.16	16
27 August	0.81	0.09	12
12 October	0.70	0.20	30
2 November	1.00	0.14	14
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 99. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.72	0.09	13	0.86	0.12	14
2 June	0.89	0.03	4	1.00	0.07	8
2 July	0.99	0.09	8	0.97	0.10	11
31 July	0.96	0.08	9	0.99	0.06	6
27 August	0.99	0.08	9	1.19	0.27	24
12 October	1.14	0.18	16	1.22	0.10	8
2 November	1.48	0.27	19	1.30	0.10	8
1 December				1.31	0.22	18

Table 99. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.82	0.13	17	0.78	0.04	6
2 June	0.99	0.15	16	0.98	0.10	11
2 July	1.04	0.08	8	1.05	0.04	4
31 July	1.09	0.12	11	1.01	0.04	4
27 August	1.21	0.12	10	1.38	0.07	5
12 October	1.46	0.20	14	1.36	0.21	16
2 November	1.78	0.29	17	1.58	0.33	22
1 December				1.38	0.16	12

Table 99. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.80	0.11	14
2 June	0.83	0.06	7
2 July	0.94	0.08	9
31 July	0.98	0.07	8
27 August	1.19	0.13	11
12 October	1.33	0.08	6
2 November	1.65	0.38	24
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 100. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.045	0.002	4	0.047	0.006	13
2 June	0.046	0.002	4	0.048	0.004	8
2 July	0.042	0.003	7	0.051	0.005	11
31 July	0.043	0.003	8	0.052	0.006	11
27 August	0.044	0.003	8	0.042	0.004	9
12 October	0.081	0.006	7	0.085	0.006	8
2 November	0.076	0.030	42	0.075	0.008	11
1 December				0.073	0.008	12

Table 100. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.052	0.004	7	0.040	0.005	13
2 June	0.046	0.005	12	0.043	0.008	22
2 July	0.046	0.002	4	0.043	0.003	8
31 July	0.050	0.005	11	0.045	0.007	17
27 August	0.064	0.016	26	0.061	0.008	15
12 October	0.093	0.011	13	0.077	0.007	9
2 November	0.074	0.002	3	0.079	0.005	8
1 December				0.089	0.006	7

Table 100. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.041	0.003	8
2 June	0.040	0.004	10
2 July	0.043	0.004	11
31 July	0.044	0.003	6
27 August	0.040	0.002	5
12 October	0.058	0.010	17
2 November	0.051	0.025	51
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 101. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.042	0.010	26	0.061	0.006	10
2 June	0.048	0.017	37	0.063	0.005	8
2 July	0.051	0.017	34	0.063	0.012	20
31 July	0.048	0.006	12	0.059	0.007	13
27 August	0.071	0.013	19	0.088	0.012	14
12 October	0.058	0.025	45	0.107	0.040	40
2 November	0.065	0.008	13	0.093	0.016	18
1 December				0.086	0.013	16

Table 101. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.052	0.005	9	0.061	0.004	6
2 June	0.049	0.007	14	0.059	0.007	12
2 July	0.049	0.005	10	0.062	0.005	9
31 July	0.054	0.003	5	0.060	0.006	11
27 August	0.083	0.004	5	0.078	0.019	25
12 October	0.099	0.027	29	0.118	0.015	13
2 November	0.094	0.025	27	0.118	0.018	16
1 December				0.100	0.007	7

Table 101. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.045	0.008	19
2 June	0.048	0.007	16
2 July	0.049	0.004	8
31 July	0.063	0.009	15
27 August	0.086	0.012	14
12 October	0.056	0.006	11
2 November	0.069	0.006	9
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean (n = 6)

Table 102. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.052	0.015	26	0.083	0.012	15
2 June	0.072	0.007	10	0.089	0.008	9
2 July	0.069	0.010	15	0.081	0.010	13
31 July	0.075	0.007	10	0.085	0.006	7
27 August	0.085	0.026	31	0.110	0.019	18
12 October	0.088	0.013	16	0.114	0.009	8
2 November	0.110	0.010	9	0.133	0.017	14
1 December				0.124	0.023	19

Table 102. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.078	0.020	27	0.086	0.007	9
2 June	0.087	0.021	26	0.093	0.014	16
2 July	0.077	0.008	11	0.102	0.009	10
31 July	0.085	0.010	12	0.098	0.008	9
27 August	0.114	0.012	11	0.136	0.016	12
12 October	0.135	0.021	16	0.142	0.025	18
2 November	0.163	0.021	13	0.168	0.020	12
1 December				0.139	0.018	13

Table 102. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.062	0.012	20
2 June	0.064	0.007	12
2 July	0.073	0.007	10
31 July	0.079	0.006	9
27 August	0.117	0.017	16
12 October	0.113	0.015	14
2 November	0.135	0.017	13
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 103. Mean percent total potassium mass (o.d.w., w/w) at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.056	0.005	9	0.056	0.007	13
2 June	0.047	0.005	12	0.053	0.003	6
2 July	0.047	0.010	21	0.068	0.004	7
31 July	0.051	0.009	19	0.066	0.009	14
27 August	0.048	0.009	19	0.047	0.002	5
12 October	0.039	0.007	19	0.044	0.004	10
2 November	0.036	0.008	24	0.049	0.010	20
1 December				0.051	0.008	19

Table 103. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.065	0.010	16	0.068	0.008	13
2 June	0.050	0.007	14	0.059	0.009	18
2 July	0.048	0.004	9	0.056	0.006	11
31 July	0.052	0.009	19	0.067	0.024	37
27 August	0.045	0.007	16	0.045	0.007	16
12 October	0.058	0.013	24	0.057	0.006	11
2 November	0.060	0.023	40	0.067	0.012	23
1 December				0.069	0.015	23

Table 103. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.045	0.005	11
2 June	0.035	0.003	8
2 July	0.040	0.005	13
31 July	0.038	0.004	10
27 August	0.041	0.009	23
12 October	0.055	0.016	31
2 November	0.066	0.023	37
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 104. Mean percent total potassium mass (o.d.w., w/w) at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.046	0.018	41	0.073	0.009	12
2 June	0.056	0.019	36	0.078	0.028	38
2 July	0.075	0.013	18			
31 July	0.043	0.010	24	0.064	0.012	20
27 August	0.072	0.018	26	0.102	0.009	9
12 October	0.089	0.021	24	0.159	0.009	6
2 November	0.085	0.008	10	0.111	0.024	23
1 December				0.112	0.016	15

Table 104. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.060	0.010	17	0.079	0.013	18
2 June	0.062	0.006	10	0.087	0.007	9
2 July	0.078	0.009	12	0.098	0.020	21
31 July	0.059	0.005	8	0.071	0.014	20
27 August	0.088	0.008	10	0.094	0.015	17
12 October	0.188	0.067	38	0.176	0.010	6
2 November	0.112	0.021	19	0.155	0.026	18
1 December				0.132	0.018	14

Table 104. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.051	0.016	32
2 June	0.065	0.006	10
2 July	0.071	0.004	6
31 July	0.094	0.046	51
27 August	0.077	0.024	32
12 October	0.089	0.016	18
2 November	0.099	0.017	18
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 105. Mean percent total potassium mass (o.d.w., w/w) at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.058	0.022	40	0.102	0.010	10
2 June	0.059	0.010	17	0.085	0.005	6
2 July	0.054	0.014	27	0.113	0.017	16
31 July	0.052	0.004	9	0.081	0.009	11
27 August	0.054	0.006	12	0.077	0.009	12
12 October	0.067	0.014	22	0.088	0.007	9
2 November	0.072	0.029	42	0.078	0.016	21
1 December				0.068	0.016	25

Table 105. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.072	0.014	20	0.134	0.024	20
2 June	0.069	0.017	26	0.106	0.006	6
2 July	0.063	0.008	13	0.117	0.026	23
31 July	0.083	0.028	36	0.107	0.018	18
27 August	0.091	0.031	36	0.098	0.016	17
12 October	0.130	0.041	33	0.101	0.016	20
2 November	0.110	0.024	23	0.141	0.007	6
1 December				0.093	0.011	12

Table 105. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.064	0.013	22
2 June	0.060	0.009	15
2 July	0.061	0.006	11
31 July	0.088	0.038	45
27 August	0.065	0.011	18
12 October	0.097	0.025	27
2 November	0.085	0.025	36
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$). calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean (n = 6)

Table 106. Mean percent total calcium mass (o.d.w., w/w) at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.51	0.02	5	0.51	0.03	6
2 June	0.48	0.02	4	0.48	0.02	5
2 July	0.48	0.03	6	0.47	0.02	4
31 July	0.48	0.03	6	0.48	0.02	5
27 August	0.51	0.04	8	0.57	0.03	6
12 October	0.57	0.05	9	0.60	0.03	5
2 November	0.56	0.04	7	0.64	0.04	7
1 December				0.60	0.03	6

Table 106. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.48	0.03	7	0.45	0.04	10
2 June	0.44	0.04	10	0.45	0.05	13
2 July	0.48	0.03	7	0.44	0.06	13
31 July	0.49	0.02	5	0.44	0.06	13
27 August	0.52	0.05	10	0.49	0.03	7
12 October	0.55	0.02	5	0.55	0.04	7
2 November	0.53	0.03	5	0.56	0.07	15
1 December				0.58	0.01	2

Table 106. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.51	0.03	6
2 June	0.54	0.03	6
2 July	0.48	0.04	8
31 July	0.53	0.03	6
27 August	0.55	0.04	7
12 October	0.58	0.02	4
2 November	0.61	0.02	3
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 107. Mean percent total calcium mass (o.d.w., w/w) at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	1.10	0.11	11	1.11	0.05	5
2 June	1.12	0.04	4	1.19	0.08	7
2 July	1.15	0.05	5			
31 July	1.22	0.13	11	1.25	0.10	8
27 August	1.17	0.09	7	1.25	0.05	4
12 October	1.23	0.07	6	1.31	0.04	3
2 November	1.12	0.10	9	1.20	0.16	14
1 December				1.26	0.12	10

Table 107. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	1.06	0.05	5	1.08	0.06	6
2 June	1.15	0.08	7	1.15	0.06	5
2 July	1.24	0.08	7	1.18	0.05	5
31 July	1.26	0.06	5	1.28	0.03	2
27 August	1.21	0.08	7	1.11	0.15	14
12 October	1.27	0.10	8	1.37	0.09	7
2 November	1.20	0.14	12	1.29	0.08	7
1 December				1.41	0.12	9

Table 107. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	1.10	0.04	4
2 June	1.20	0.05	4
2 July	1.17	0.07	6
31 July	1.26	0.09	8
27 August	1.37	0.30	23
12 October	1.29	0.08	6
2 November	1.26	0.09	7
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 108. Mean percent total calcium mass (o.d.w., w/w) at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	1.38	0.14	11	1.34	0.07	6
2 June	1.20	0.06	5	1.26	0.08	7
2 July	1.27	0.06	5	1.23	0.10	9
31 July	1.19	0.07	6	1.23	0.08	7
27 August	1.24	0.09	7	1.26	0.04	3
12 October	1.14	0.16	14	1.17	0.05	5
2 November	1.15	0.09	8	1.17	0.11	10
1 December				1.23	0.12	11

Table 108. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	1.14	0.10	9	0.91	0.03	4
2 June	1.15	0.10	9	0.96	0.04	4
2 July	1.09	0.15	14	0.94	0.03	4
31 July	1.13	0.15	14	0.96	0.04	4
27 August	1.11	0.22	21	1.01	0.14	14
12 October	1.00	0.18	18	1.09	0.24	27
2 November	1.09	0.18	18	1.06	0.09	9
1 December				1.15	0.11	10

Table 108. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	1.42	0.16	11
2 June	1.18	0.05	5
2 July	1.26	0.06	5
31 July	1.28	0.14	12
27 August	1.33	0.10	8
12 October	1.25	0.11	9
2 November	1.13	0.14	15
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 109. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.088	0.007	8	0.088	0.005	6
2 June	0.075	0.006	8	0.077	0.005	7
2 July	0.073	0.006	8	0.073	0.004	6
31 July	0.069	0.007	11	0.077	0.006	8
27 August	0.062	0.007	12	0.070	0.003	5
12 October	0.056	0.008	15	0.064	0.006	10
2 November	0.050	0.009	19	0.071	0.008	12
1 December				0.066	0.006	10

Table 109. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.088	0.004	4	0.092	0.004	5
2 June	0.075	0.005	8	0.083	0.006	9
2 July	0.068	0.004	7	0.071	0.004	6
31 July	0.065	0.006	9	0.077	0.012	16
27 August	0.069	0.006	10	0.069	0.002	3
12 October	0.060	0.009	16	0.061	0.003	6
2 November	0.061	0.005	9	0.069	0.016	28
1 December				0.066	0.002	3

Table 109. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.091	0.004	4
2 June	0.077	0.005	6
2 July	0.069	0.003	5
31 July	0.061	0.004	7
27 August	0.061	0.010	18
12 October	0.059	0.005	8
2 November	0.066	0.006	9
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 110. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.100	0.019	20	0.108	0.005	5
2 June	0.083	0.013	16	0.096	0.013	15
2 July	0.085	0.008	10			
31 July	0.087	0.011	14	0.109	0.017	16
27 August	0.069	0.013	21	0.092	0.009	10
12 October	0.072	0.020	30	0.093	0.007	8
2 November	0.071	0.017	25	0.092	0.017	20
1 December				0.103	0.022	22

Table 110. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.106	0.009	9	0.116	0.008	7
2 June	0.095	0.004	4	0.119	0.010	8
2 July	0.092	0.011	13	0.109	0.014	13
31 July	0.094	0.014	16	0.111	0.006	5
27 August	0.079	0.003	4	0.084	0.011	14
12 October	0.104	0.019	19	0.090	0.009	11
2 November	0.098	0.008	8	0.097	0.010	11
1 December				0.102	0.012	12

Table 110. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.109	0.008	8
2 June	0.098	0.006	6
2 July	0.087	0.005	6
31 July	0.089	0.011	13
27 August	0.085	0.031	38
12 October	0.086	0.007	9
2 November	0.086	0.019	23
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 111. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
30 April	0.106	0.009	9	0.115	0.005	4
2 June	0.073	0.011	16	0.094	0.003	4
2 July	0.066	0.007	12	0.107	0.014	14
31 July	0.054	0.010	19	0.094	0.009	10
27 August	0.052	0.008	15	0.093	0.004	4
12 October	0.053	0.018	36	0.100	0.023	24
2 November	0.056	0.021	40	0.096	0.016	18
1 December				0.104	0.012	12

Table 111. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
30 April	0.098	0.010	10	0.090	0.002	3
2 June	0.075	0.007	10	0.085	0.009	11
2 July	0.065	0.010	16	0.083	0.009	11
31 July	0.065	0.005	8	0.086	0.006	7
27 August	0.063	0.015	25	0.088	0.013	15
12 October	0.081	0.013	16	0.088	0.021	29
2 November	0.095	0.013	14	0.101	0.012	12
1 December				0.104	0.005	5

Table 111. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.104	0.006	6
2 June	0.079	0.007	9
2 July	0.076	0.006	9
31 July	0.074	0.016	22
27 August	0.062	0.006	10
12 October	0.068	0.016	25
2 November	0.078	0.023	36
1 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 112. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot: Plantation Mean	S.D.[a]	%[b]	Antenna Plot: Hardwood Stand Mean	S.D.	%
7 May	0.55	0.03	6	0.50	0.05	11
3 June	0.53	0.03	5	0.53	0.02	4
1 July	0.57	0.04	8	0.56	0.04	7
30 July	0.62	0.06	11	0.57	0.03	6
4 September	0.70	0.03	4	0.68	0.02	2
1 October	0.46	0.03	7	0.44	0.06	15
6 November	0.66	0.09	15	0.68	0.06	9
6 December				1.17	0.10	9

Table 112. (cont)

Sampling Date	Control Plot: Plantation Mean	S.D.	%	Control Plot: Hardwood Stand Mean	S.D.	%
7 May	0.53	0.05	9	0.53	0.06	12
3 June	0.53	0.03	6	0.52	0.03	7
1 July	0.59	0.04	7	0.56	0.04	8
30 July	0.60	0.03	6	0.57	0.03	6
4 September	0.73	0.07	10	0.71	0.07	10
1 October	0.59	0.07	13	0.61	0.03	5
6 November	0.72	0.08	12	0.64	0.09	14
6 December				1.34	0.09	7

Table 112. (cont)

Sampling Date	Ground Plot: Plantation Mean	S.D.	%
7 May	0.53	0.02	5
3 June	0.61	0.05	9
1 July	0.66	0.03	4
30 July	0.61	0.05	9
4 September	0.77	0.05	7
1 October	0.59	0.10	17
6 November	0.67	0.06	9
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 113. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.85	0.09	11	0.84	0.08	9
3 June	0.83	0.05	6	0.79	0.05	6
1 July	0.92	0.06	7	0.90	0.09	10
30 July	0.93	0.06	7	0.89	0.05	6
4 September	1.03	0.13	13	0.96	0.05	5
1 October	1.14	0.13	12	1.14	0.06	5
6 November	1.15	0.09	8	1.16	0.06	6
6 December				0.66	0.05	9

Table 113. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.78	0.05	7	0.74	0.04	6
3 June	0.82	0.03	4	0.89	0.04	5
1 July	0.89	0.04	5	0.90	0.06	7
30 July	1.02	0.09	9	0.91	0.03	3
4 September	1.03	0.07	7	1.01	0.11	12
1 October	1.21	0.10	9	1.06	0.05	5
6 November	1.19	0.07	6	1.12	0.07	7
6 December				1.04	0.30	30

Table 113. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.88	0.05	6
3 June	0.87	0.04	5
1 July	0.89	0.08	10
30 July	0.95	0.09	9
4 September	1.13	0.04	4
1 October	1.04	0.11	11
6 November	1.18	0.06	5
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 114. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	1.05	0.05	5	1.02	0.14	15
3 June	1.03	0.03	3	1.04	0.05	5
1 July	1.29	0.21	17	1.10	0.10	10
30 July	1.31	0.12	10	1.13	0.06	6
4 September	1.45	0.14	10	1.26	0.09	7
1 October	1.39	0.08	8	1.31	0.19	15
6 November	1.40	0.09	6	1.24	0.09	8
6 December				1.30	0.12	9

Table 114. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	1.14	0.15	14	1.11	0.10	10
3 June	1.07	0.07	7	1.09	0.14	14
1 July	1.21	0.07	6	1.18	0.11	10
30 July	1.32	0.25	20	1.16	0.19	17
4 September	1.39	0.10	7	1.28	0.13	10
1 October	1.51	0.14	11	1.29	0.13	10
6 November	1.57	0.15	10	1.35	0.13	10
6 December				0.66	0.08	12

Table 114. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	1.03	0.06	7
3 June	1.06	0.11	11
1 July	1.35	0.08	6
30 July	1.31	0.14	11
4 September	1.44	0.07	5
1 October	1.51	0.09	6
6 November	1.51	0.12	13
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 115. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.043	0.003	7	0.043	0.004	11
3 June	0.043	0.004	9	0.047	0.003	6
1 July	0.053	0.010	21	0.050	0.004	8
30 July	0.044	0.004	9	0.050	0.003	7
4 September	0.035	0.005	14	0 047	0.007	15
1 October	0.042	0.008	19	0.048	0.005	12
6 November	0.050	0.011	23	0.059	0.006	12
6 December				0.091	0.013	15

Table 115. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.049	0.006	13	0.045	0.005	12
3 June	0.046	0.011	25	0.045	0.004	9
1 July	0.048	0.003	7	0.049	0.004	7
30 July	0.045	0.003	8	0.048	0.002	4
4 September	0.049	0.005	10	0.051	0.005	11
1 October	0.044	0.004	9	0.050	0.005	10
6 November	0.046	0.008	17	0.052	0.012	24
6 December				0.101	0.008	9

Table 115. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.041	0.002	6
3 June	0.048	0.005	10
1 July	0.051	0.002	4
30 July	0.043	0.003	8
4 September	0.041	0.005	14
1 October	0.041	0.007	17
6 November	0.048	0.004	8
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 116. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.055	0.005	10	0.055	0.004	7
3 June	0.059	0.007	13	0.060	0.005	9
1 July	0.054	0.001	2	0.061	0.006	10
30 July	0.058	0.005	9	0.064	0.012	19
4 September	0.057	0.006	12	0.064	0.008	13
1 October	0.067	0.011	17	0.082	0.008	10
6 November	0.059	0.008	14	0.086	0.010	13
6 December				0.066	0.017	27

Table 116. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.045	0.005	12	0.043	0.003	8
3 June	0.059	0.003	5	0.046	0.002	5
1 July	0.053	0.004	8	0.055	0.006	12
30 July	0.057	0.006	10	0.052	0.002	4
4 September	0.065	0.006	9	0.061	0.006	11
1 October	0.074	0.010	14	0.074	0.007	11
6 November	0.074	0.006	8	0.088	0.010	12
6 December				0.079	0.016	21

Table 116. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.050	0.003	7
3 June	0.059	0.005	8
1 July	0.051	0.010	20
30 July	0.054	0.006	12
4 September	0.064	0.005	9
1 October	0.056	0.008	15
6 November	0.059	0.003	6
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 117. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.082	0.008	10	0.086	0.013	16
3 June	0.083	0.005	7	0.087	0.003	3
1 July	0.091	0.012	14	0.088	0.010	11
30 July	0.089	0.008	9	0.089	0.006	8
4 September	0.092	0.010	12	0.101	0.008	9
1 October	0.086	0.011	13	0.111	0.015	14
6 November	0.082	0.008	12	0.094	0.010	11
6 December				0.092	0.011	12

Table 117. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.086	0.013	16	0.087	0.008	9
3 June	0.093	0.007	8	0.095	0.010	11
1 July	0.086	0.006	8	0.096	0.011	12
30 July	0.096	0.017	18	0.098	0.013	14
4 September	0.106	0.005	5	0.103	0.008	8
1 October	0.106	0.008	10	0.107	0.008	8
6 November	0.103	0.013	13	0.109	0.012	12
6 December				0.059	0.009	16

Table 117. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.079	0.005	7
3 June	0.079	0.008	11
1 July	0.097	0.008	9
30 July	0.095	0.013	15
4 September	0.086	0.006	8
1 October	0.091	0.005	6
6 November	0.100	0.010	16
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 118. Mean percent total potassium mass (o.d.w., w/w) at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.040	0.005	13	0.043	0.007	18
3 June	0.055	0.006	11	0.068	0.008	13
1 July	0.059	0.030	52	0.058	0.006	10
30 July	0.040	0.006	17	0.055	0.006	12
4 September	0.029	0.006	22	0 035	0.004	11
1 October	0.029	0.004	15	0.054	0.006	12
6 November	0.040	0.021	55	0.055	0.013	25
6 December				0.057	0.011	20

Table 118. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.048	0.017	36	0.066	0.007	11
3 June	0.045	0.002	4	0.049	0.006	14
1 July	0.050	0.014	30	0.054	0.007	14
30 July	0.050	0.018	37	0.050	0.005	10
4 September	0.039	0.008	23	0.038	0.007	18
1 October	0.038	0.018	50	0.047	0.008	17
6 November	0.042	0.012	30	0.070	0.018	27
6 December				0.066	0.011	18

Table 118. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.040	0.007	19
3 June	0.065	0.011	18
1 July	0.044	0.005	12
30 July	0.036	0.004	12
4 September	0.034	0.017	54
1 October	0.024	0.006	28
6 November	0.035	0.008	25
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 119. Mean percent total potassium mass (o.d.w., w/w) at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.059	0.007	13	0.066	0.011	17
3 June	0.051	0.005	10	0.073	0.013	18
1 July	0.060	0.009	17	0.068	0.008	13
30 July	0.067	0.012	19	0.065	0.006	9
4 September	0.051	0.003	6	0.076	0.008	12
1 October	0.081	0.016	21	0.113	0.012	11
6 November	0.071	0.010	15	0.115	0.017	15
6 December				0.110	0.018	17

Table 119. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.054	0.006	11	0.052	0.009	18
3 June	0.065	0.015	24	0.056	0.003	7
1 July	0.070	0.014	22	0.068	0.010	16
30 July	0.066	0.013	21	0.067	0.004	6
4 September	0.086	0.024	30	0.074	0.006	9
1 October	0.091	0.008	9	0.108	0.013	13
6 November	0.082	0.014	18	0.111	0.019	18
6 December				0.122	0.010	8

Table 119. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.061	0.008	14
3 June	0.055	0.004	8
1 July	0.059	0.004	8
30 July	0.062	0.008	13
4 September	0.060	0.008	14
1 October	0.060	0.010	18
6 November	0.071	0.010	16
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 120. Mean percent total potassium mass (o.d.w., w/w) at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.084	0.005	6	0.109	0.016	15
3 June	0.082	0.012	15	0.094	0.005	5
1 July	0.083	0.015	18	0.108	0.016	15
30 July	0.063	0.009	15	0.068	0.005	8
4 September	0.059	0.013	23	0.073	0.011	16
1 October	0.073	0.017	25	0.095	0.011	13
6 November	0.055	0.008	17	0.094	0.009	10
6 December				0.106	0.027	26

Table 120. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.095	0.017	18	0.099	0.013	14
3 June	0.087	0.008	9	0.083	0.007	8
1 July	0.087	0.012	14	0.086	0.009	12
30 July	0.072	0.003	5	0.075	0.004	6
4 September	0.076	0.019	26	0.071	0.006	9
1 October	0.089	0.012	17	0.105	0.014	14
6 November	0.096	0.013	14	0.103	0.019	20
6 December				0.127	0.014	12

Table 120. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.092	0.012	14
3 June	0.090	0.021	24
1 July	0.077	0.015	20
30 July	0.069	0.008	12
4 September	0.062	0.011	19
1 October	0.086	0.029	36
6 November	0.077	0.008	17
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 121. Mean percent total calcium mass (o.d.w., w/w) at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.36	0.03	7	0.34	0.03	10
3 June	0.45	0.03	8	0.45	0.04	9
1 July	0.47	0.03	7	0.47	0.04	10
30 July	0.44	0.02	6	0.46	0.04	8
4 September	0.43	0.05	12	0 49	0.03	7
1 October	0.47	0.05	11	0.54	0.03	7
6 November	0.44	0.05	11	0.46	0.04	10
6 December				0.54	0.06	12

Table 121. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.40	0.11	28	0.50	0.08	16
3 June	0.41	0.03	8	0.44	0.03	7
1 July	0.47	0.04	8	0.47	0.04	10
30 July	0.47	0.03	7	0.45	0.03	6
4 September	0.44	0.02	5	0.49	0.03	7
1 October	0.55	0.07	13	0.54	0.04	7
6 November	0.49	0.03	6	0.52	0.06	12
6 December				0.55	0.03	6

Table 121. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.41	0.04	9
3 June	0.52	0.04	9
1 July	0.53	0.06	12
30 July	0.44	0.04	10
4 September	0.46	0.04	10
1 October	0.54	0.03	6
6 November	0.49	0.05	10
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean (n = 6)

Table 122. Mean percent total calcium mass (o.d.w., w/w) at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.99	0.06	7	1.11	0.03	3
3 June	1.16	0.04	3	1.12	0.07	6
1 July	1.15	0.06	6	1.05	0.04	4
30 July	1.05	0.06	6	1.10	0.05	5
4 September	1.15	0.05	5	1.19	0.05	5
1 October	1.24	0.11	10	1.25	0.09	8
6 November	1.18	0.10	9	1.27	0.08	6
6 December				1.27	0.09	7

Table 122. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	1.11	0.04	4	1.05	0.06	6
3 June	1.11	0.04	4	1.14	0.07	6
1 July	1.13	0.04	4	1.13	0.04	4
30 July	1.13	0.06	6	1.16	0.06	6
4 September	1.24	0.08	7	1.19	0.05	4
1 October	1.29	0.09	7	1.28	0.08	7
6 November	1.25	0.06	5	1.22	0.04	4
6 December				1.23	0.07	6

Table 122. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	1.01	0.06	6
3 June	1.15	0.03	3
1 July	1.17	0.04	4
30 July	1.07	0.06	6
4 September	1.17	0.05	5
1 October	1.14	0.07	6
6 November	1.18	0.04	4
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 123. Mean percent total calcium mass (o.d.w., w/w) at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	1.10	0.10	10	1.14	0.08	7
3 June	1.17	0.12	10	1.16	0.04	4
1 July	1.15	0.13	12	1.15	0.06	6
30 July	1.11	0.05	5	1.13	0.08	7
4 September	1.09	0.07	7	1.22	0.06	5
1 October	0.95	0.07	8	1.04	0.20	20
6 November	1.07	0.08	10	1.12	0.08	8
6 December				1.20	0.09	8

Table 123. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	1.05	0.07	7	1.09	0.12	11
3 June	1.12	0.10	9	1.17	0.14	12
1 July	1.09	0.04	3	1.15	0.12	11
30 July	1.06	0.07	7	1.03	0.12	12
4 September	1.24	0.10	8	1.20	0.15	13
1 October	0.92	0.12	16	1.02	0.06	6
6 November	1.20	0.11	10	1.16	0.05	5
6 December				1.19	0.08	7

Table 123. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	1.14	0.07	7
3 June	1.03	0.07	7
1 July	1.18	0.10	8
30 July	1.15	0.03	2
4 September	1.18	0.08	7
1 October	1.18	0.01	1
6 November	1.10	0.13	18
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 124. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.083	0.008	10	0.085	0.005	6
3 June	0.077	0.009	12	0.090	0.009	10
1 July	0.062	0.008	13	0.075	0.006	8
30 July	0.064	0.008	13	0.071	0.005	8
4 September	0.046	0.002	4	0 059	0.006	11
1 October	0.044	0.007	17	0.058	0.004	8
6 November	0.051	0.015	31	0.057	0.009	17
6 December				0.056	0.015	29

Table 124. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.081	0.009	11	0.092	0.011	12
3 June	0.067	0.008	13	0.076	0.004	6
1 July	0.062	0.003	6	0.069	0.010	16
30 July	0.060	0.009	15	0.066	0.005	8
4 September	0.051	0.009	18	0.065	0.008	12
1 October	0.048	0.010	21	0.059	0.010	18
6 November	0.050	0.012	26	0.056	0.008	15
6 December				0.054	0.005	9

Table 124. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.086	0.007	9
3 June	0.089	0.009	10
1 July	0.074	0.006	9
30 July	0.059	0.009	16
4 September	0.049	0.010	21
1 October	0.048	0.013	28
6 November	0.041	0.008	20
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 125. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.135	0.016	12	0.118	0.004	3
3 June	0.106	0.006	6	0.118	0.006	5
1 July	0.104	0.013	13	0.114	0.005	5
30 July	0.088	0.008	10	0.094	0.006	6
4 September	0.079	0.006	8	0.097	0.006	7
1 October	0.081	0.014	18	0.097	0.009	9
6 November	0.081	0.011	14	0.100	0.017	18
6 December				0.096	0.027	30

Table 125. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.111	0.005	5	0.114	0.006	6
3 June	0.113	0.006	6	0.122	0.005	4
1 July	0.106	0.008	7	0.112	0.005	5
30 July	0.088	0.009	11	0.099	0.006	6
4 September	0.105	0.033	32	0.097	0.002	3
1 October	0.088	0.006	8	0.090	0.006	7
6 November	0.089	0.005	5	0.093	0.008	9
6 December				0.095	0.005	6

Table 125. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.141	0.009	7
3 June	0.110	0.003	3
1 July	0.115	0.004	4
30 July	0.088	0.006	7
4 September	0.085	0.007	9
1 October	0.076	0.008	11
6 November	0.073	0.009	14
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 126. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.132	0.003	2	0.144	0.005	4
3 June	0.108	0.014	13	0.114	0.006	6
1 July	0.086	0.007	8	0.103	0.010	10
30 July	0.073	0.007	10	0.088	0.007	9
4 September	0.064	0.009	15	0.099	0.014	15
1 October	0.063	0.016	26	0.093	0.019	22
6 November	0.070	0.023	40	0.097	0.012	13
6 December				0.110	0.023	22

Table 126. (cont)

Sampling Date	Control Plot					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
7 May	0.144	0.006	4	0.144	0.009	7
3 June	0.102	0.008	9	0.110	0.010	9
1 July	0.084	0.008	11	0.097	0.011	12
30 July	0.081	0.009	11	0.087	0.007	9
4 September	0.092	0.021	24	0.098	0.014	15
1 October	0.080	0.013	20	0.095	0.007	8
6 November	0.093	0.011	13	0.101	0.007	7
6 December				0.103	0.008	8

Table 126. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.136	0.009	7
3 June	0.102	0.007	7
1 July	0.104	0.005	5
30 July	0.082	0.006	8
4 September	0.065	0.008	14
1 October	0.072	0.010	14
6 November	0.076	0.020	41
6 December			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 127. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1987, for bulk red pine foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.38	0.02	4	0.39	0.05	12
27 May						
25 June	0.42	0.04	11	0.38	0.01	3
23 July						
27 August	0.59	0.03	5	0.48	0.01	3
24 September						
28 October	0.60	0.03	5	0.57	0.05	8
25 November						

Table 127. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.40	0.06	15	0.39	0.03	9
27 May						
25 June	0.41	0.06	15	0.48	0.02	4
23 July						
27 August	0.54	0.03	7	0.59	0.08	14
24 September						
28 October	0.60	0.06	10	0.61	0.03	5
25 November						

Table 127. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.40	0.05	14
27 May			
25 June	0.47	0.04	9
23 July			
27 August	0.58	0.03	6
24 September			
28 October	0.63	0.08	13
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 128. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1987, for bulk red oak foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.55	0.23	44	0.47	0.08	17
27 May						
25 June	0.62	0.10	17	0.74	0.11	15
23 July						
27 August	0.71	0.09	14	0.73	0.05	8
24 September						
28 October	0.68	0.05	7	0.73	0.08	12
25 November						

Table 128. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.48	0.08	17	0.50	0.05	11
27 May						
25 June	0.68	0.04	7	0.61	0.04	6
23 July						
27 August	0.78	0.05	7	0.71	0.06	9
24 September						
28 October	0.87	0.07	8	0.77	0.06	8
25 November						

Table 128. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.41	0.04	11
27 May			
25 June	0.60	0.04	8
23 July			
27 August	0.70	0.05	7
24 September			
28 October	0.74	0.10	14
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 129. Mean percent total nitrogen mass (o.d.w., w/w) at different times in 1987, for bulk red maple foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.61	0.07	12	0.57	0.06	10
27 May						
25 June	0.73	0.06	9	0.76	0.07	10
23 July						
27 August	0.96	0.06	6	0.95	0.03	3
24 September						
28 October	1.00	0.06	6	0.97	0.05	6
25 November						

Table 129. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.54	0.05	10	0.57	0.13	24
27 May						
25 June	0.84	0.05	7	0.76	0.06	8
23 July						
27 August	1.05	0.05	5	0.95	0.10	11
24 September						
28 October	1.04	0.11	11	0.94	0.09	10
25 November						

Table 129. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.59	0.04	8
27 May			
25 June	0.67	0.07	11
23 July			
27 August	0.96	0.05	5
24 September			
28 October	1.04	0.11	11
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean (n = 6)

Table 130. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1987, for bulk red pine foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.039	0.003	7	0.042	0.004	11
27 May						
25 June	0.072	0.010	14	0.053	0.003	5
23 July						
27 August	0.034	0.003	8	0.031	0.002	6
24 September						
28 October	0.047	0.010	22	0.051	0.006	12
25 November						

Table 130. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.037	0.006	16	0.040	0.007	18
27 May						
25 June	0.038	0.007	20	0.046	0.003	7
23 July						
27 August	0.032	0.002	6	0.040	0.007	19
24 September						
28 October	0.041	0.006	16	0.043	0.005	11
25 November						

Table 130. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.040	0.006	15
27 May			
25 June	0.070	0.009	14
23 July			
27 August	0.034	0.002	5
24 September			
28 October	0.044	0.004	10
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 131. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1987, for bulk red oak foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.064	0.030	49	0.058	0.010	18
27 May						
25 June	0.055	0.011	22	0.058	0.007	13
23 July						
27 August	0.059	0.007	12	0.063	0.003	5
24 September						
28 October	0.060	0.008	14	0.074	0.009	12
25 November						

Table 131. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.063	0.011	18	0.069	0.004	6
27 May						
25 June	0.069	0.005	8	0.064	0.010	16
23 July						
27 August	0.061	0.004	7	0.061	0.011	18
24 September						
28 October	0.080	0.010	13	0.086	0.016	19
25 November						

Table 131. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.058	0.005	10
27 May			
25 June	0.049	0.006	12
23 July			
27 August	0.063	0.004	6
24 September			
28 October	0.064	0.006	10
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 132. Mean percent total phosphorus mass (o.d.w., w/w) at different times in 1987, for bulk red maple foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.053	0.006	12	0.052	0.010	19
27 May						
25 June	0.052	0.007	13	0.058	0.005	9
23 July						
27 August	0.066	0.005	8	0.071	0.004	6
24 September						
28 October	0.067	0.004	7	0.070	0.007	11
25 November						

Table 132. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.048	0.005	10	0.044	0.005	11
27 May						
25 June	0.061	0.004	7	0.059	0.002	4
23 July						
27 August	0.070	0.008	12	0.073	0.006	9
24 September						
28 October	0.071	0.012	17	0.079	0.011	15
25 November						

Table 132. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.052	0.001	3
27 May			
25 June	0.050	0.006	13
23 July			
27 August	0.066	0.008	13
24 September			
28 October	0.067	0.009	15
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 133. Mean percent total potassium mass (o.d.w., w/w) at different times in 1987, for bulk red pine foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.036	0.002	6	0.039	0.005	13
27 May						
25 June	0.023	0.005	22	0.022	0.002	8
23 July						
27 August	0.032	0.005	17	0.025	0.015	61
24 September						
28 October	0.040	0.018	47	0.029	0.004	16
25 November						

Table 133. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.038	0.003	10	0.050	0.002	5
27 May						
25 June	0.027	0.005	19	0.048	0.012	27
23 July						
27 August	0.026	0.001	5	0.025	0.007	28
24 September						
28 October	0.030	0.006	21	0.048	0.019	41
25 November						

Table 133. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.038	0.003	9
27 May			
25 June	0.020	0.004	23
23 July			
27 August	0.034	0.002	7
24 September			
28 October	0.036	0.013	37
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 134. Mean percent total potassium mass (o.d.w., w/w) at different times in 1987, for bulk red oak foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.161	0.022	15	0.135	0.014	11
27 May						
25 June	0.053	0.012	23	0.057	0.011	21
23 July						
27 August	0.041	0.015	39	0.053	0.013	25
24 September						
28 October	0.051	0.013	27	0.056	0.010	18
25 November						

Table 134. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.138	0.022	17	0.175	0.013	8
27 May						
25 June	0.067	0.013	20	0.085	0.045	55
23 July						
27 August	0.051	0.004	9	0.063	0.007	12
24 September						
28 October	0.067	0.009	13	0.072	0.014	20
25 November						

Table 134. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.183	0.032	19
27 May			
25 June	0.057	0.017	31
23 July			
27 August	0.043	0.005	13
24 September			
28 October	0.059	0.010	18
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 135. Mean percent total potassium mass (o.d.w., w/w) at different times in 1987, for bulk red maple foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.063	0.011	19	0.068	0.018	28
27 May						
25 June	0.028	0.003	12	0.043	0.007	17
23 July						
27 August	0.035	0.008	24	0.039	0.007	18
24 September						
28 October	0.060	0.018	32	0.054	0.005	10
25 November						

Table 135. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.059	0.003	6	0.062	0.005	8
27 May						
25 June	0.047	0.007	15	0.046	0.004	10
23 July						
27 August	0.045	0.005	11	0.034	0.003	10
24 September						
28 October	0.065	0.009	15	0.066	0.008	12
25 November						

Table 135. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.063	0.012	19
27 May			
25 June	0.036	0.009	26
23 July			
27 August	0.045	0.004	10
24 September			
28 October	0.058	0.010	18
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 136. Mean percent total calcium mass (o.d.w., w/w) at different times in 1987, for bulk red pine foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.37	0.02	5	0.38	0.03	8
27 May						
25 June	0.40	0.01	3	0.42	0.02	6
23 July						
27 August	0.47	0.01	3	0.45	0.03	7
24 September						
28 October	0.48	0.04	8	0.49	0.04	8
25 November						

Table 136. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.40	0.02	6	0.37	0.02	7
27 May						
25 June	0.43	0.01	3	0.44	0.04	9
23 July						
27 August	0.43	0.02	5	0.51	0.05	10
24 September						
28 October	0.52	0.05	10	0.52	0.06	12
25 November						

Table 136. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.38	0.03	8
27 May			
25 June	0.44	0.03	6
23 July			
27 August	0.49	0.02	5
24 September			
28 October	0.48	0.03	6
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 137. Mean percent total calcium mass (o.d.w., w/w) at different times in 1987, for bulk red oak foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	1.03	0.08	8	1.02	0.09	9
27 May						
25 June	1.10	0.05	5	1.12	0.07	6
23 July						
27 August	1.12	0.10	10	1.22	0.05	4
24 September						
28 October	1.16	0.11	10	1.17	0.06	5
25 November						

Table 137. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.98	0.08	9	1.09	0.05	5
27 May						
25 June	1.11	0.05	4	1.14	0.06	6
27 July						
24 August	1.21	0.10	8	1.28	0.04	3
28 September						
25 October	1.25	0.07	6	1.31	0.10	8
20 November						

Table 137. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	1.10	0.06	5
27 May			
25 June	1.12	0.06	6
23 July			
27 August	1.20	0.04	3
24 September			
28 October	1.28	0.07	6
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 138. Mean percent total calcium mass (o.d.w., w/w) at different times in 1987, for bulk red maple foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.91	0.05	6	0.94	0.03	3
27 May						
25 June	1.03	0.04	4	1.06	0.06	6
23 July						
27 August	1.04	0.07	7	1.07	0.05	4
24 September						
28 October	1.12	0.08	7	1.12	0.07	6
25 November						

Table 138. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	1.03	0.03	3	0.99	0.03	3
27 May						
25 June	1.16	0.18	16	1.08	0.04	4
23 July						
27 August	1.11	0.07	6	1.00	0.05	5
24 September						
28 October	1.13	0.09	8	1.14	0.07	7
25 November						

Table 138. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.91	0.03	4
27 May			
25 June	0.98	0.07	8
23 July			
27 August	1.08	0.05	5
24 September			
28 October	1.05	0.06	6
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 139. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1987, for bulk red pine foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.072	0.005	7	0.069	0.005	8
27 May						
25 June	0.060	0.004	7	0.060	0.003	5
23 July						
27 August	0.056	0.007	12	0.050	0.003	6
24 September						
28 October	0.059	0.007	13	0.052	0.004	8
25 November						

Table 139. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.073	0.006	9	0.074	0.005	8
27 May						
25 June	0.063	0.008	14	0.076	0.005	6
23 July						
27 August	0.044	0.005	13	0.064	0.020	32
24 September						
28 October	0.053	0.006	11	0.060	0.007	12
25 November						

Table 139. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.080	0.009	11
27 May			
25 June	0.061	0.002	4
23 July			
27 August	0.056	0.005	10
24 September			
28 October	0.056	0.005	10
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 140. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1987, for bulk red oak foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.142	0.012	9	0.137	0.009	7
27 May						
25 June	0.122	0.008	7	0.129	0.014	11
23 July						
27 August	0.099	0.010	10	0.109	0.016	15
24 September						
28 October	0.117	0.023	20	0.113	0.014	13
25 November						

Table 140. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.131	0.011	9	0.154	0.007	5
27 May						
25 June	0.123	0.007	6	0.145	0.012	9
23 July						
27 August	0.106	0.007	6	0.125	0.010	9
24 September						
28 October	0.124	0.013	11	0.123	0.008	7
25 November						

Table 140. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.145	0.008	6
27 May			
25 June	0.121	0.009	7
23 July			
27 August	0.112	0.005	5
24 September			
28 October	0.119	0.017	15
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05, n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 141. Mean percent total magnesium mass (o.d.w., w/w) at different times in 1987, for bulk red maple foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
29 April	0.091	0.011	13	0.089	0.012	14
27 May						
25 June	0.065	0.007	11	0.078	0.009	12
23 July						
27 August	0.055	0.006	11	0.066	0.003	5
24 September						
28 October	0.082	0.017	22	0.092	0.009	11
25 November						

Table 141. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.	%	Mean	S.D.	%
29 April	0.083	0.004	5	0.086	0.003	4
27 May						
25 June	0.072	0.019	28	0.087	0.010	12
23 July						
27 August	0.055	0.009	18	0.072	0.007	10
24 September						
28 October	0.088	0.007	9	0.092	0.011	13
25 November						

Table 141. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.086	0.013	16
27 May			
25 June	0.063	0.008	14
23 July			
27 August	0.056	0.017	32
24 September			
28 October	0.068	0.010	16
25 November			

[a] standard deviation
[b] detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

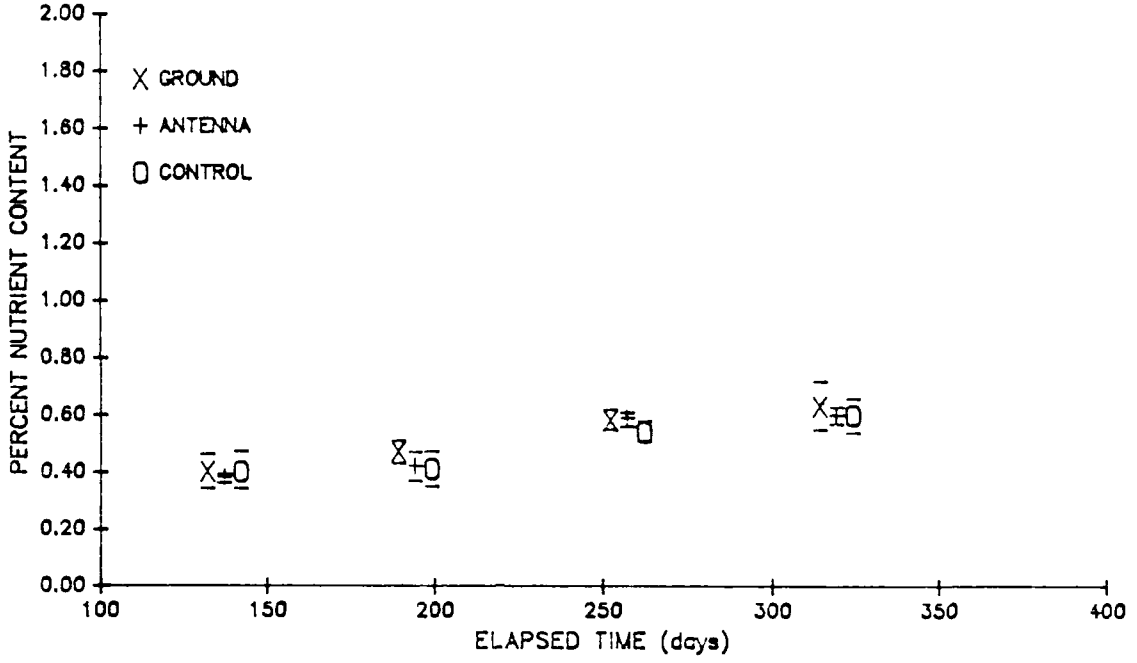

FIGURE 36. Percent nitrogen content of bulk pine needle samples retrieved from the three plantation subunits during the 1986–1987 experiment.

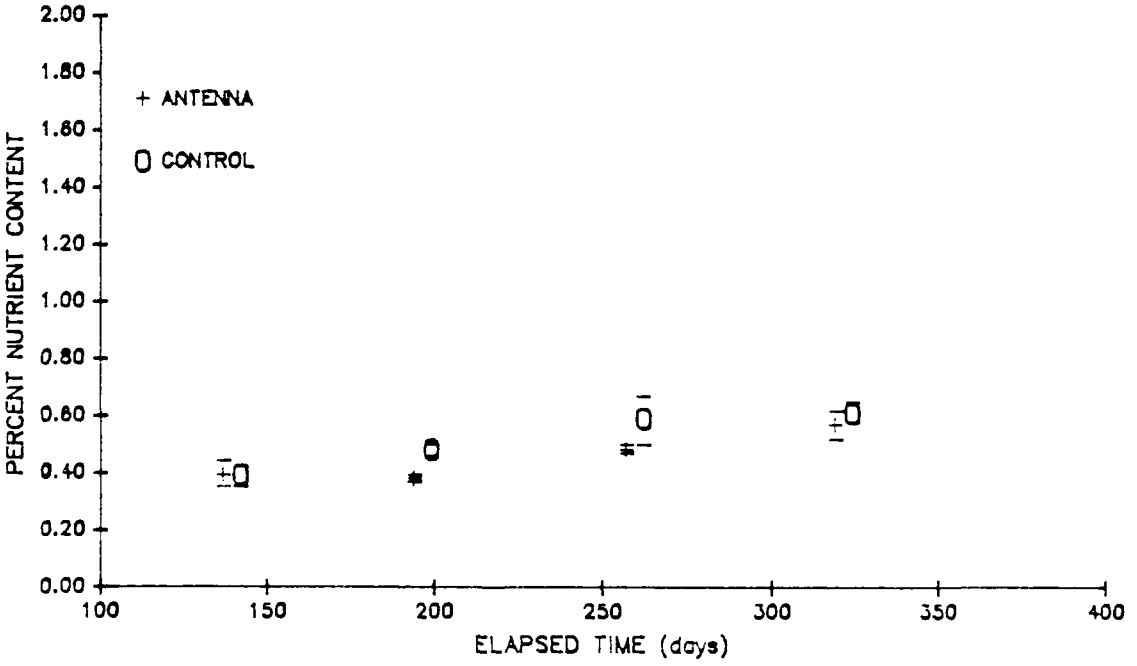

FIGURE 37. Percent nitrogen content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

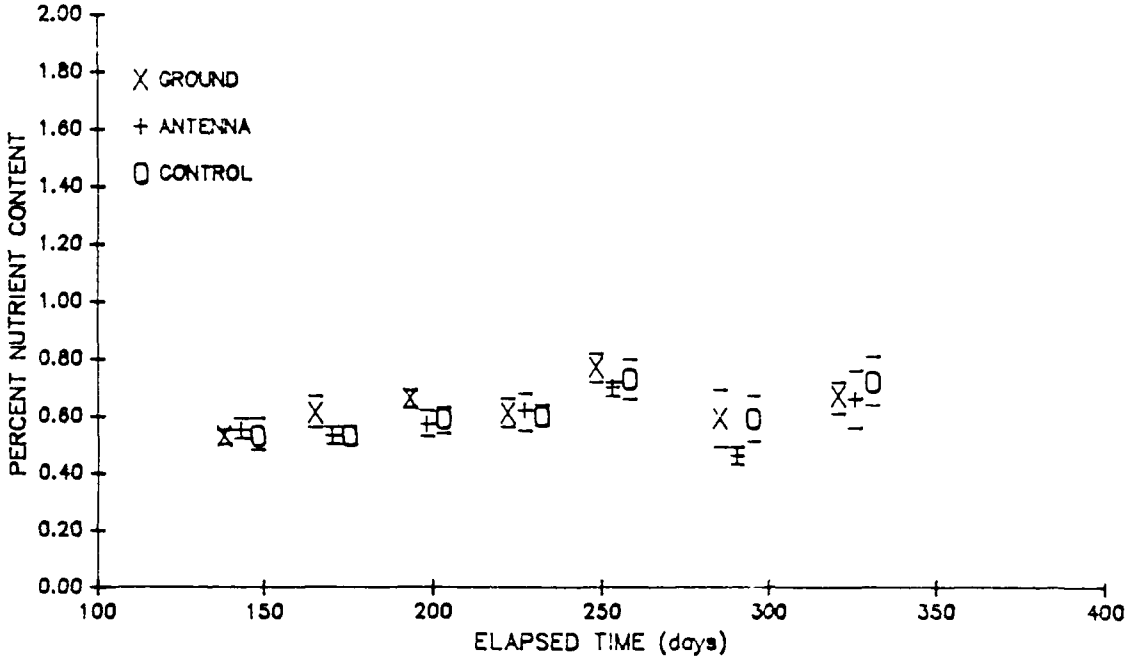

FIGURE 38. Percent nitrogen content of bulk pine needle samples retrieved from the three plantation subunits during the 1985–1986 experiment.

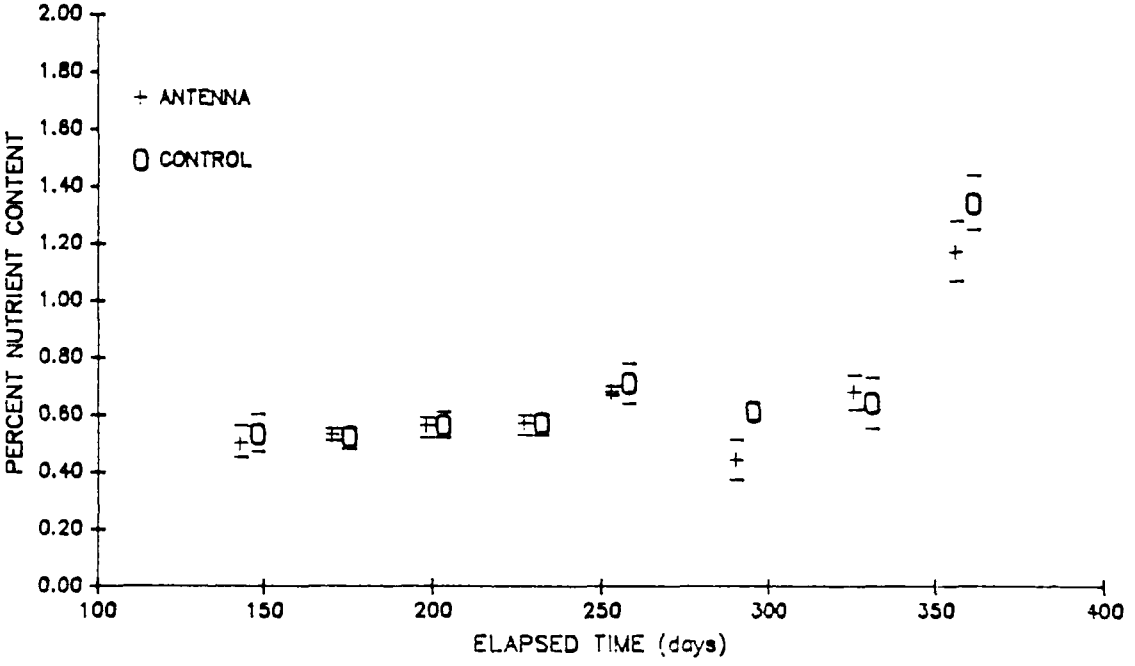

FIGURE 39. Percent nitrogen content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

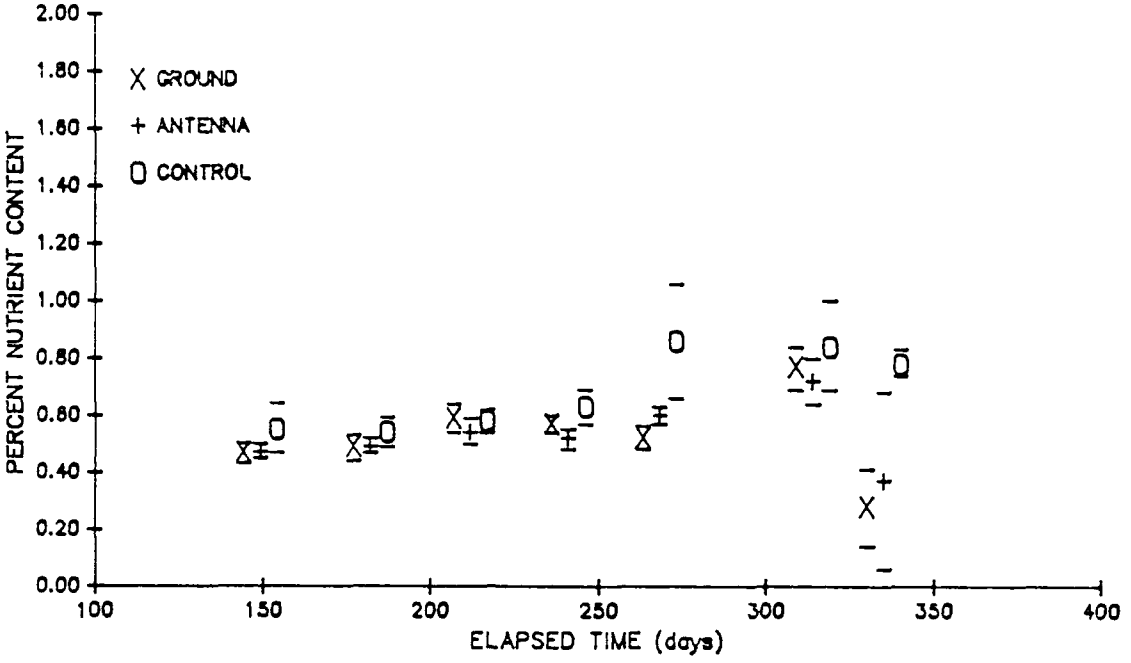

FIGURE 40. Percent nitrogen content of bulk pine needle samples retrieved from the three plantation subunits during the 1984–1985 experiment.

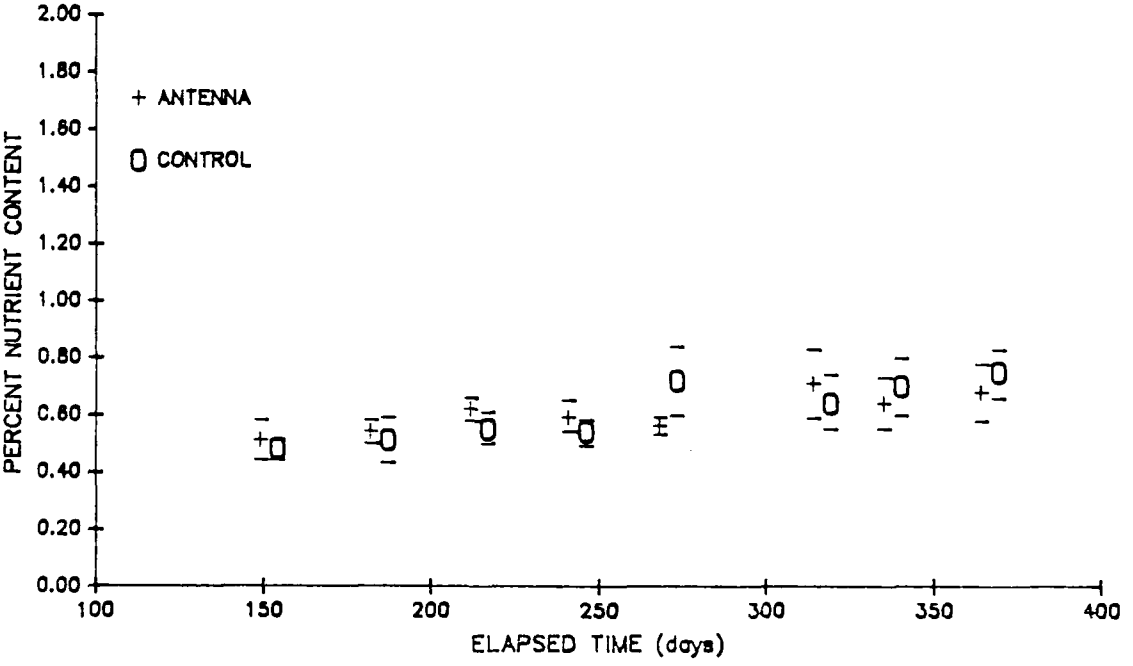

FIGURE 41. Percent nitrogen content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

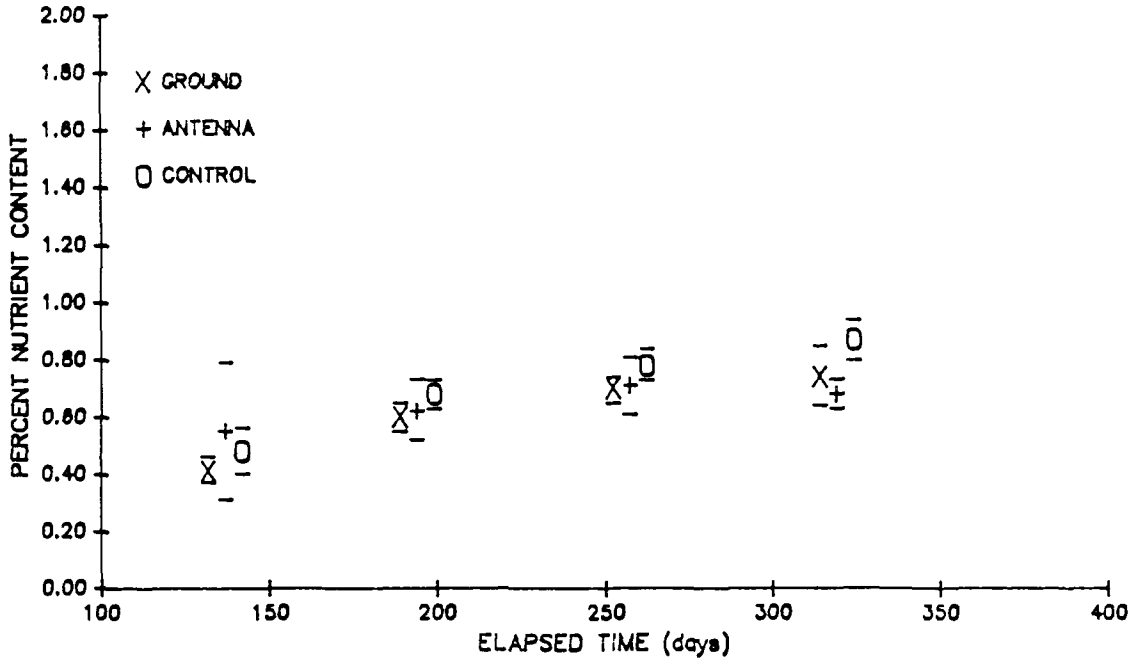

FIGURE 42. Percent nitrogen content of bulk oak leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

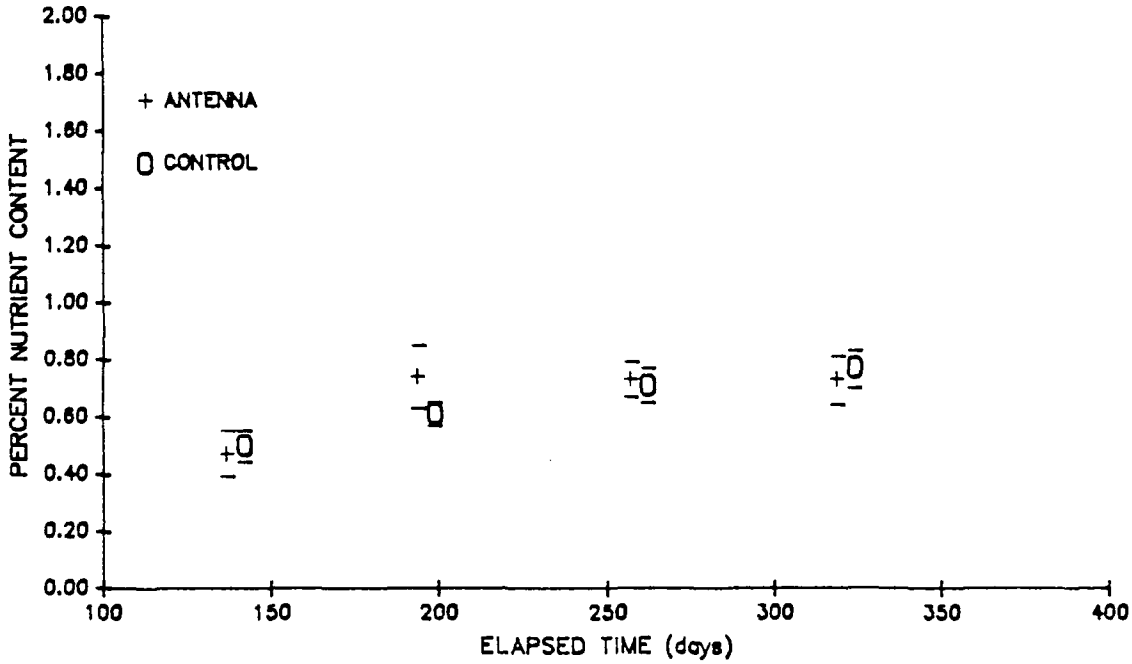

FIGURE 43. Percent nitrogen content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

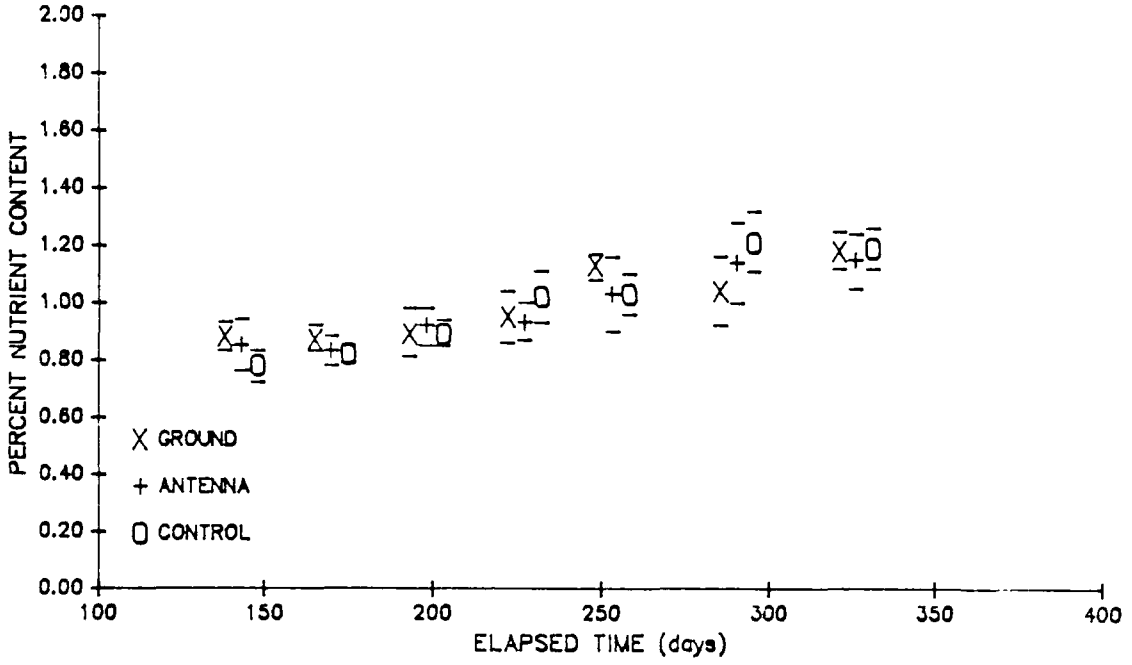

FIGURE 44. Percent nitrogen content of bulk oak leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

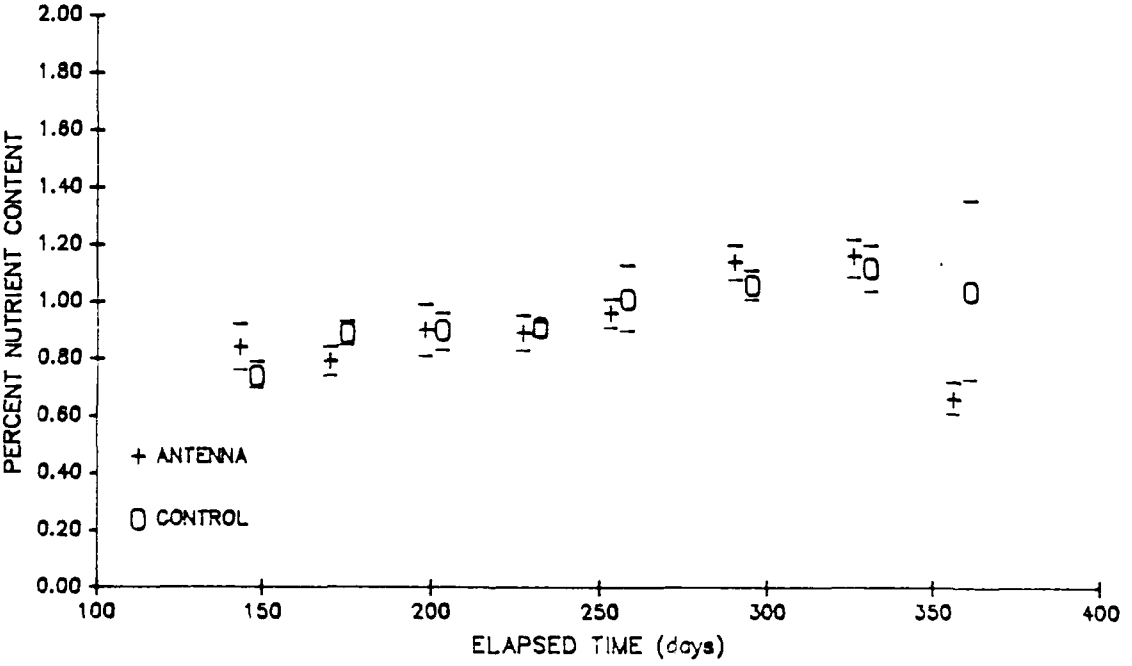

FIGURE 45. Percent nitrogen content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

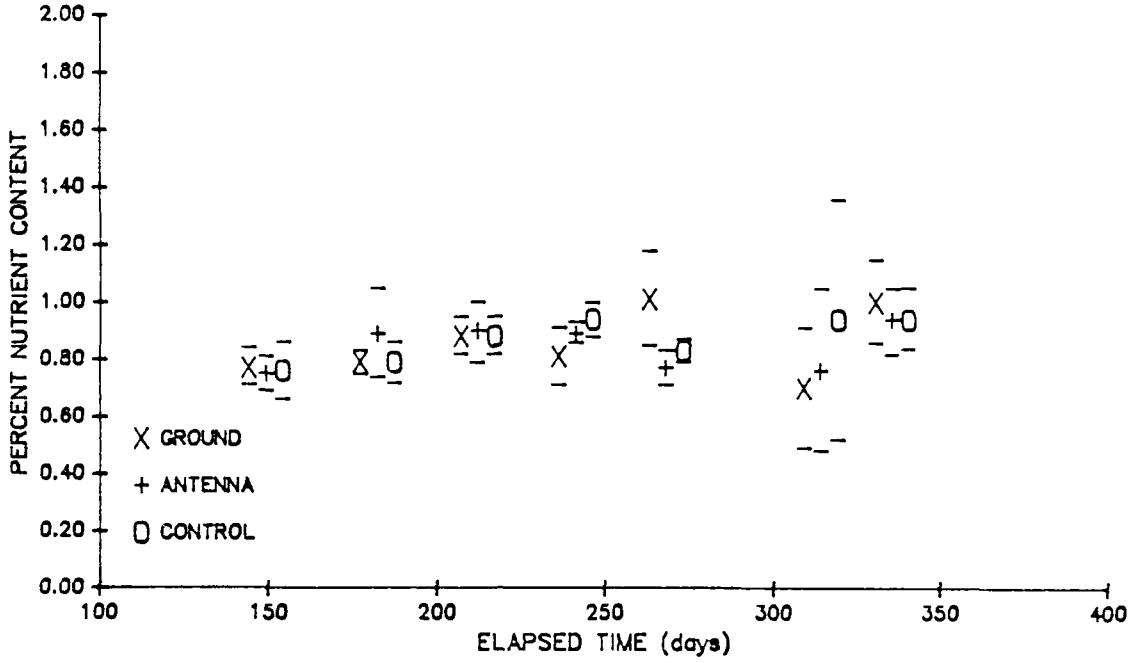

FIGURE 46. Percent nitrogen content of bulk oak leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

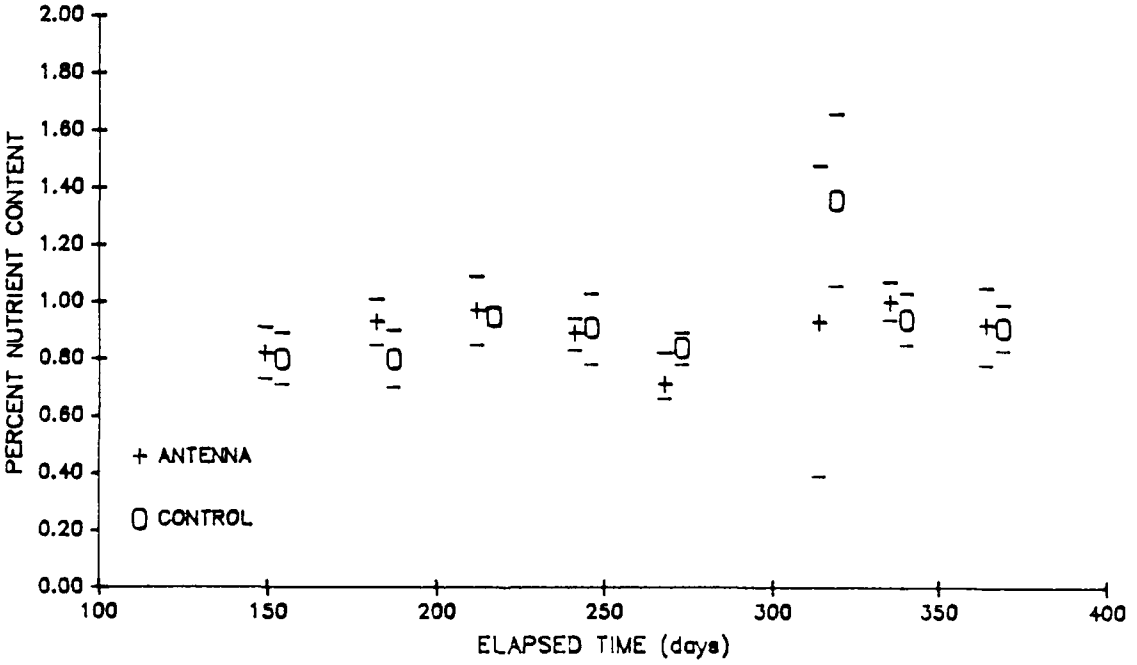

FIGURE 47. Percent nitrogen content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

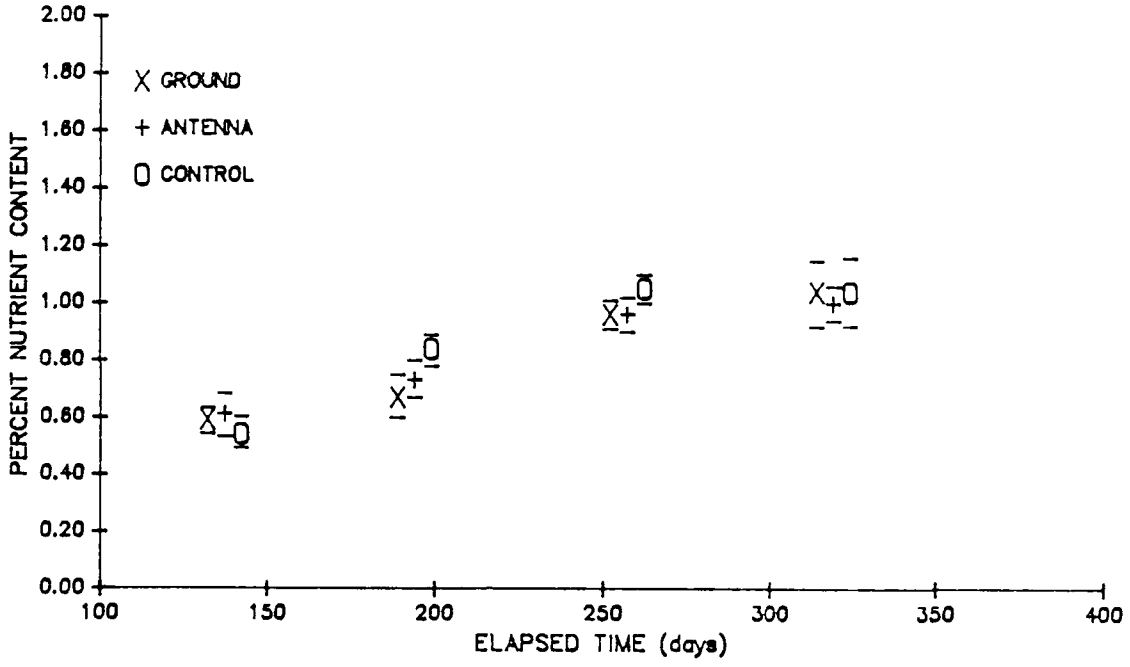

FIGURE 48. Percent nitrogen content of bulk maple leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

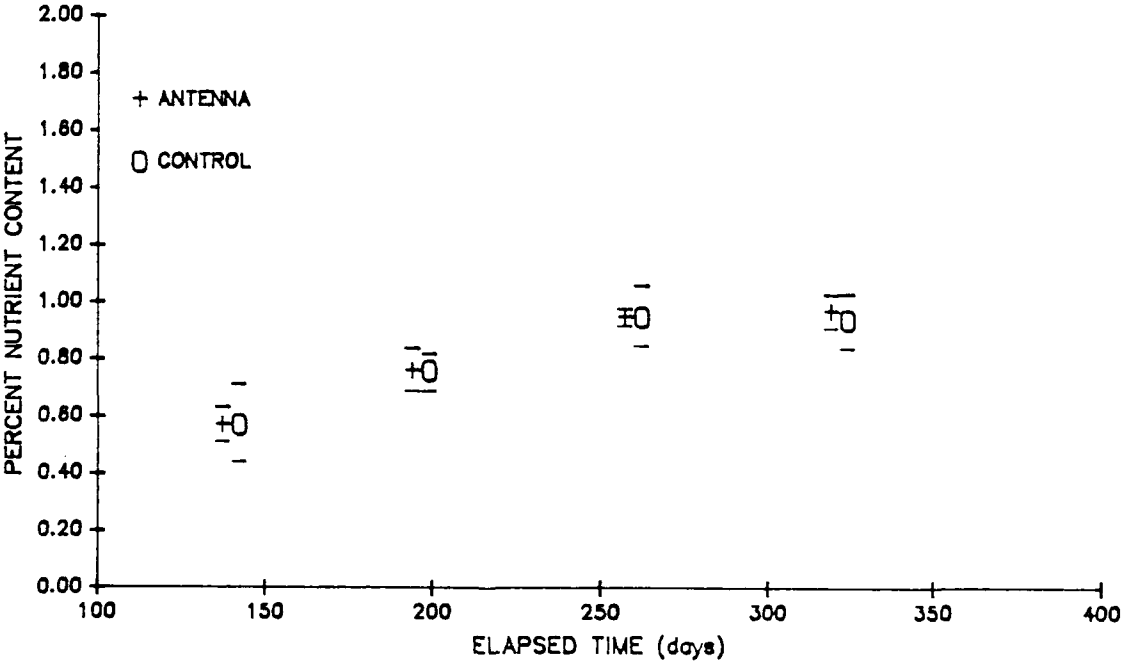

FIGURE 49. Percent nitrogen content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

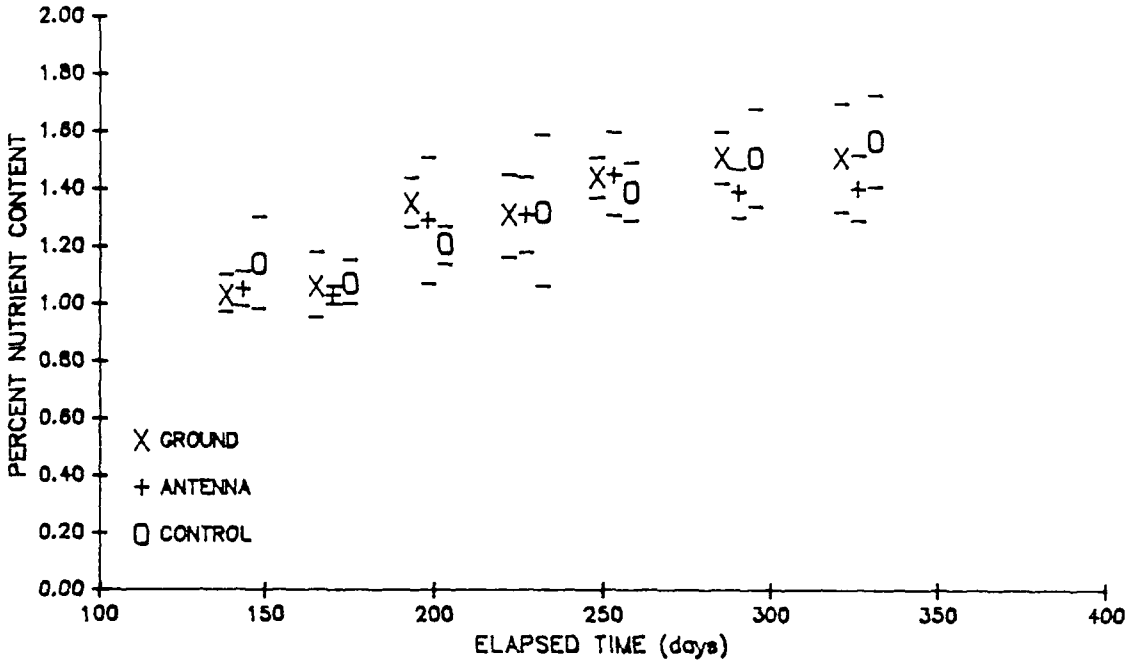

FIGURE 50. Percent nitrogen content of bulk maple leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

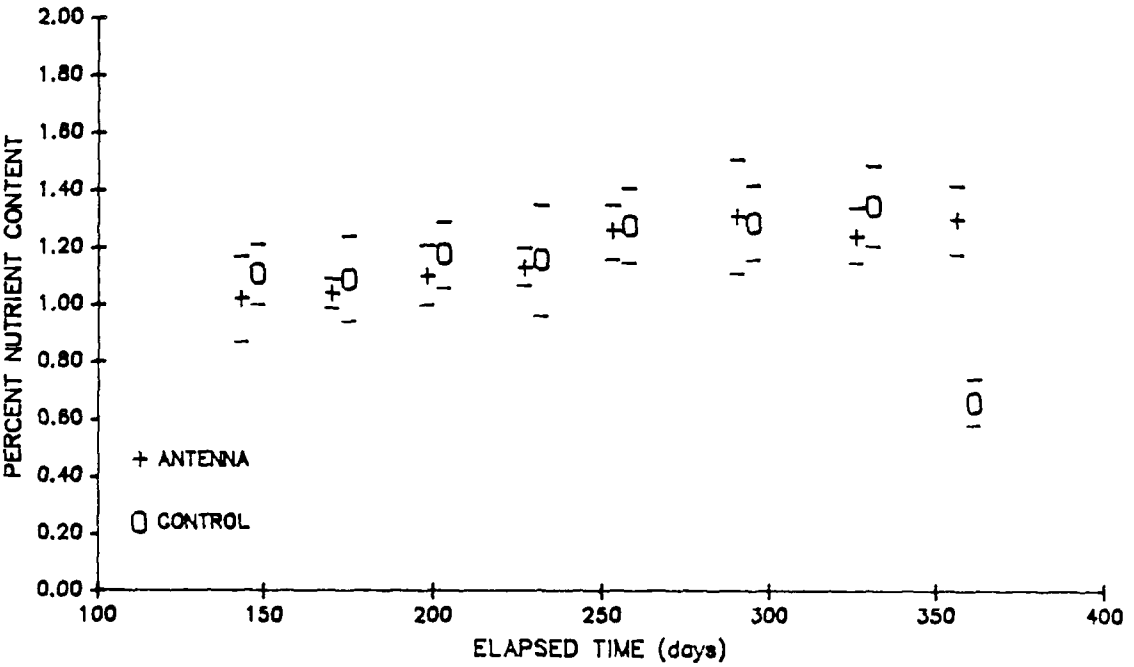

FIGURE 51. Percent nitrogen content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

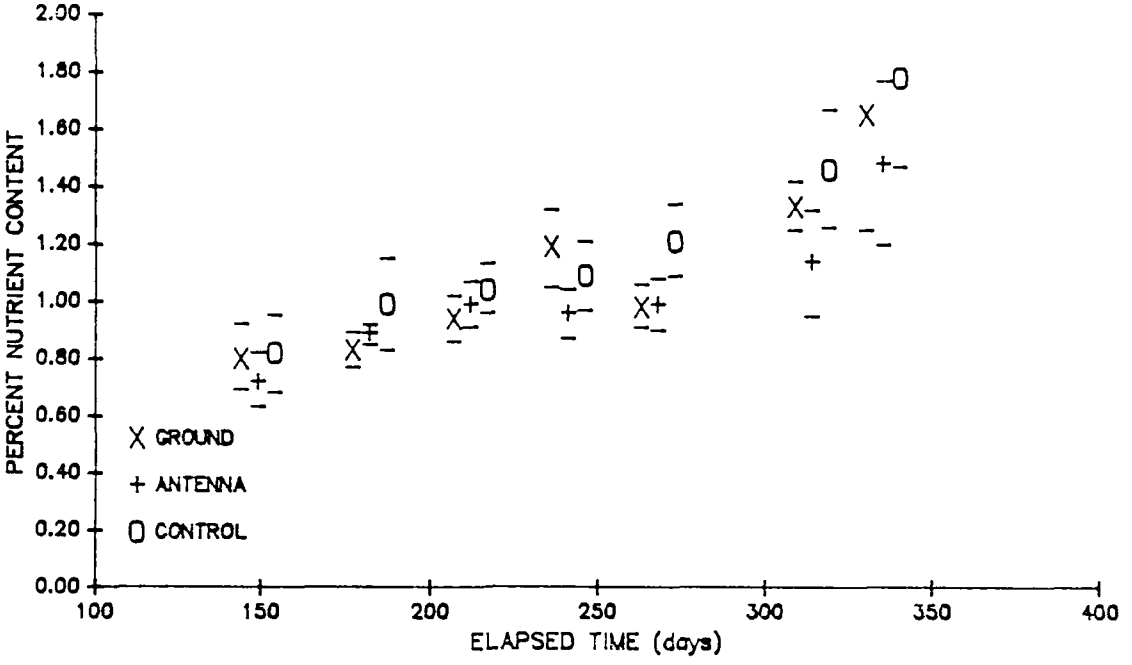

FIGURE 52. Percent nitrogen content of bulk maple leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

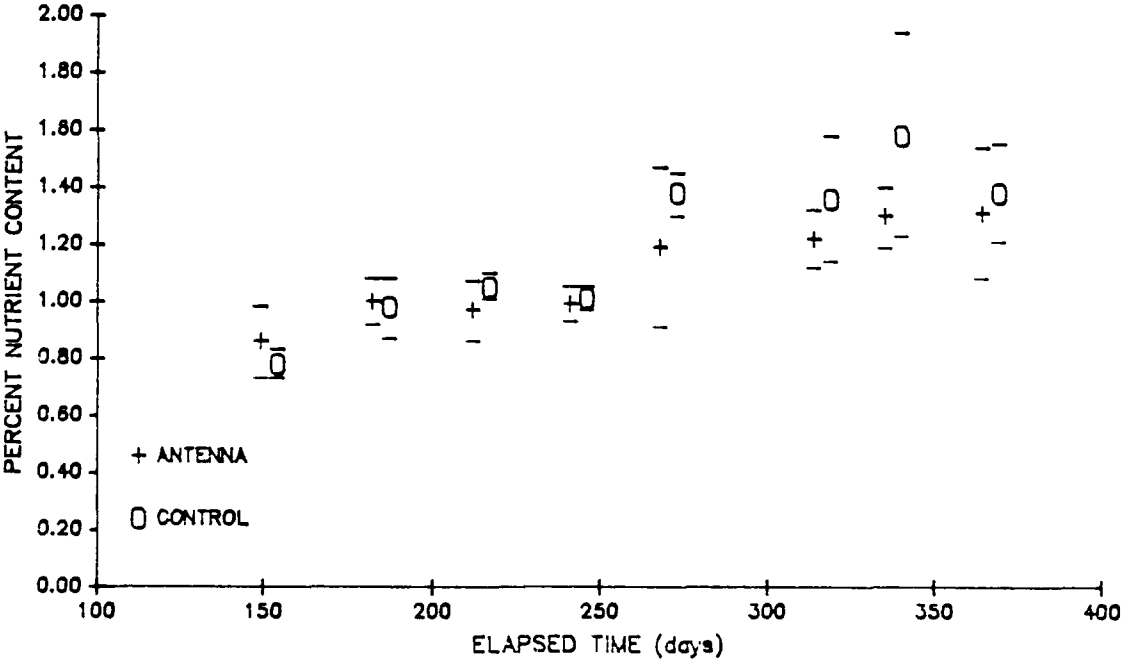

FIGURE 53. Percent nitrogen content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

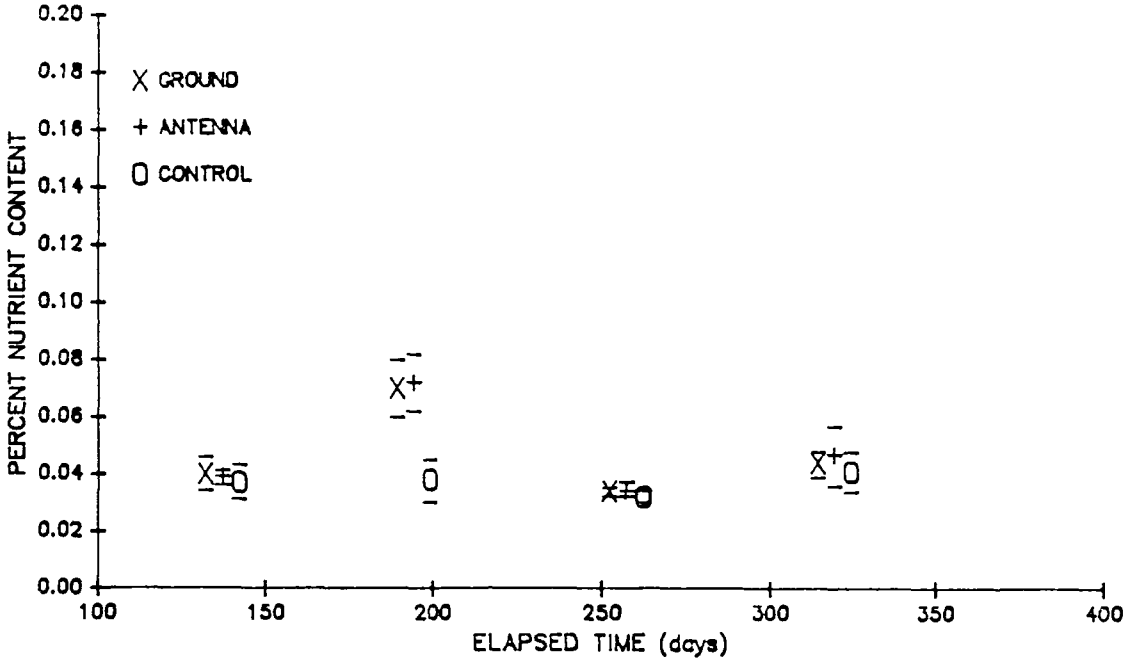

FIGURE 54. Percent phosphorus content of bulk pine needle samples retrieved from the three plantation subunits during the 1986–1987 experiment.

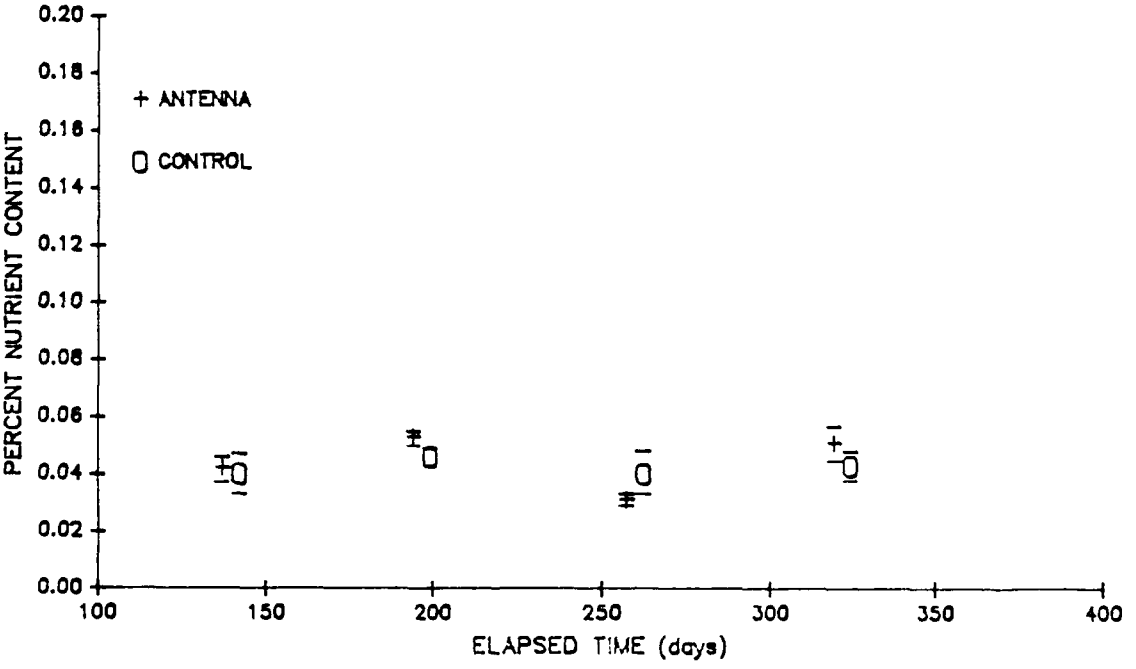

FIGURE 55. Percent phosphorus content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

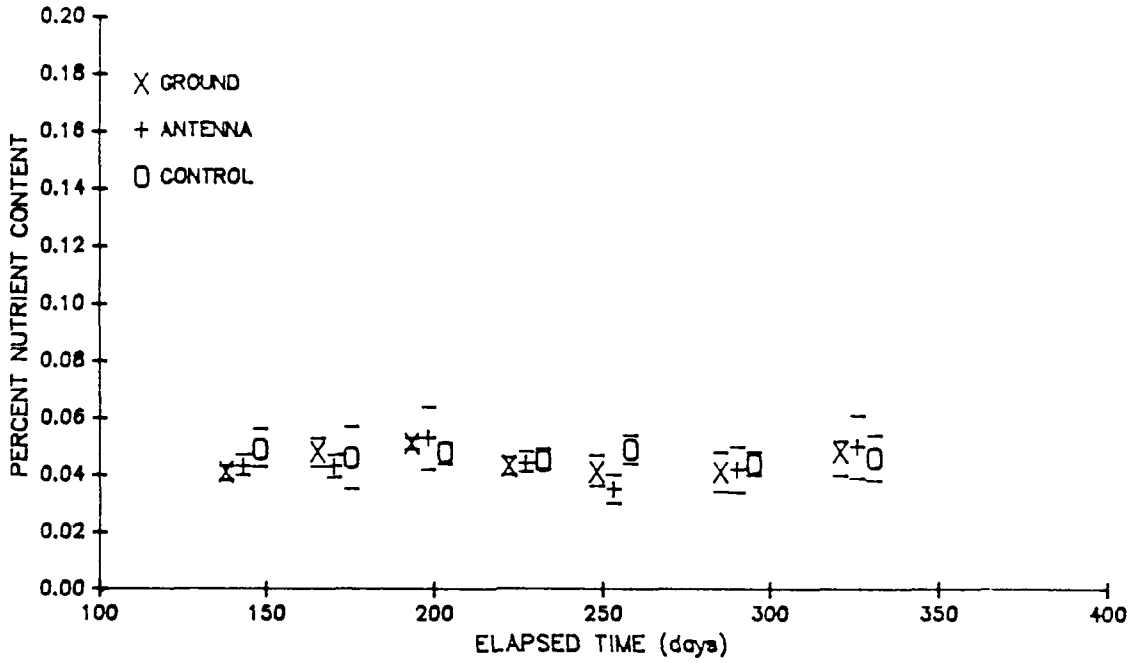

FIGURE 56. Percent phosphorus content of bulk pine needle samples retrieved from the three plantation subunits during the 1985–1986 experiment.

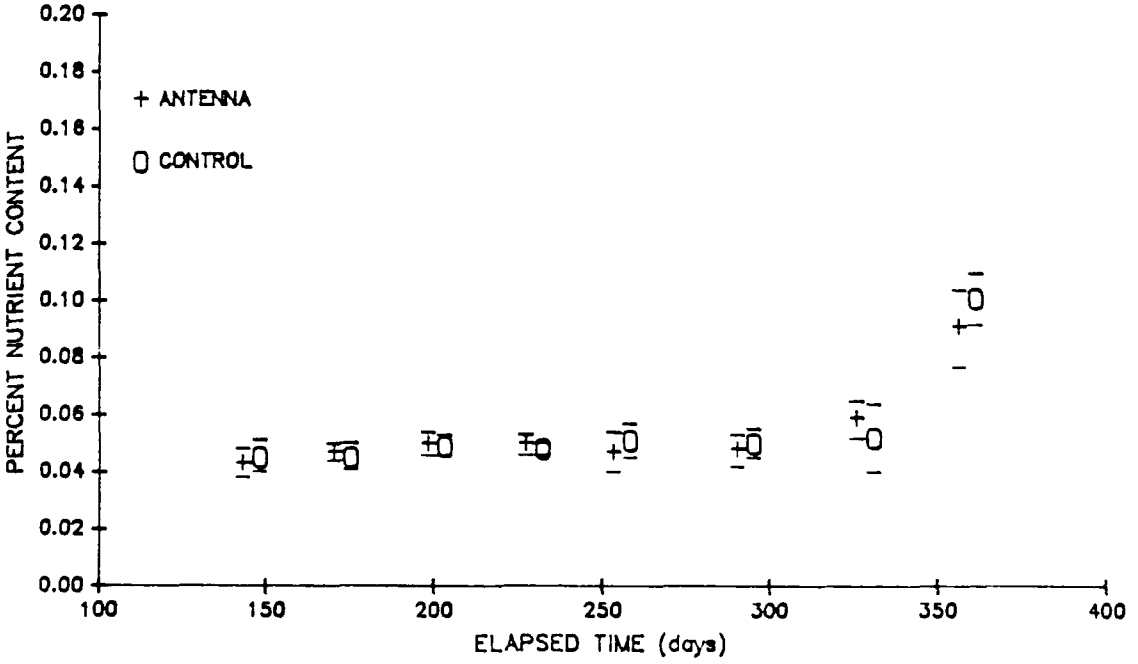

FIGURE 57. Percent phosphorus content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

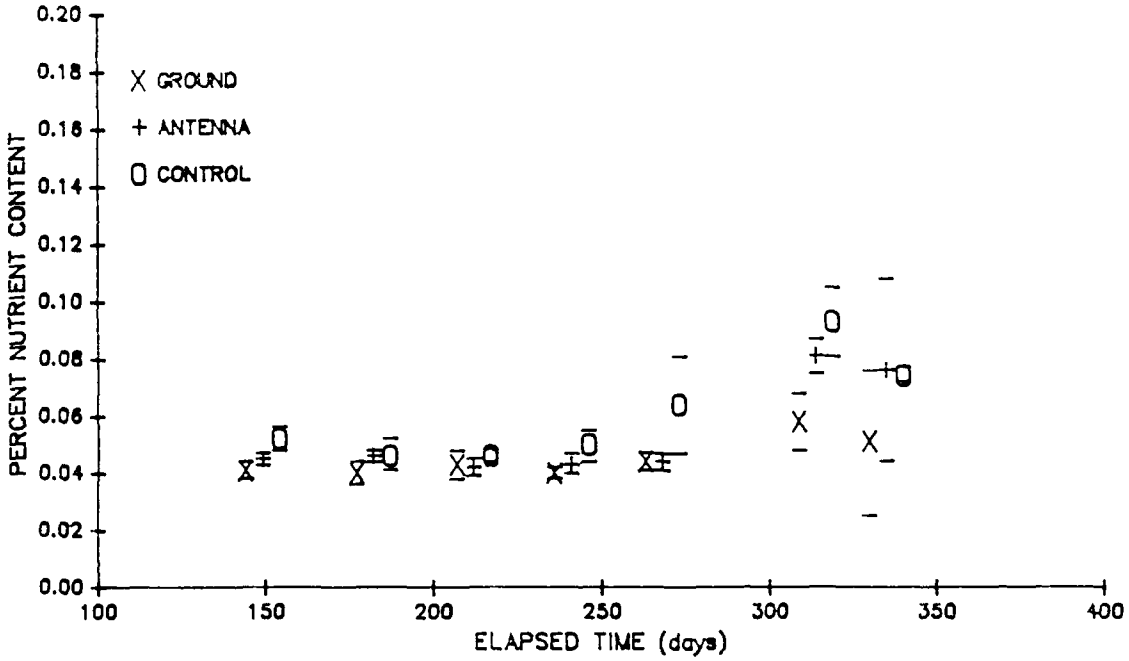

FIGURE 58. Percent phosphorus content of bulk pine needle samples retrieved from the three plantation subunits during the 1984–1985 experiment.

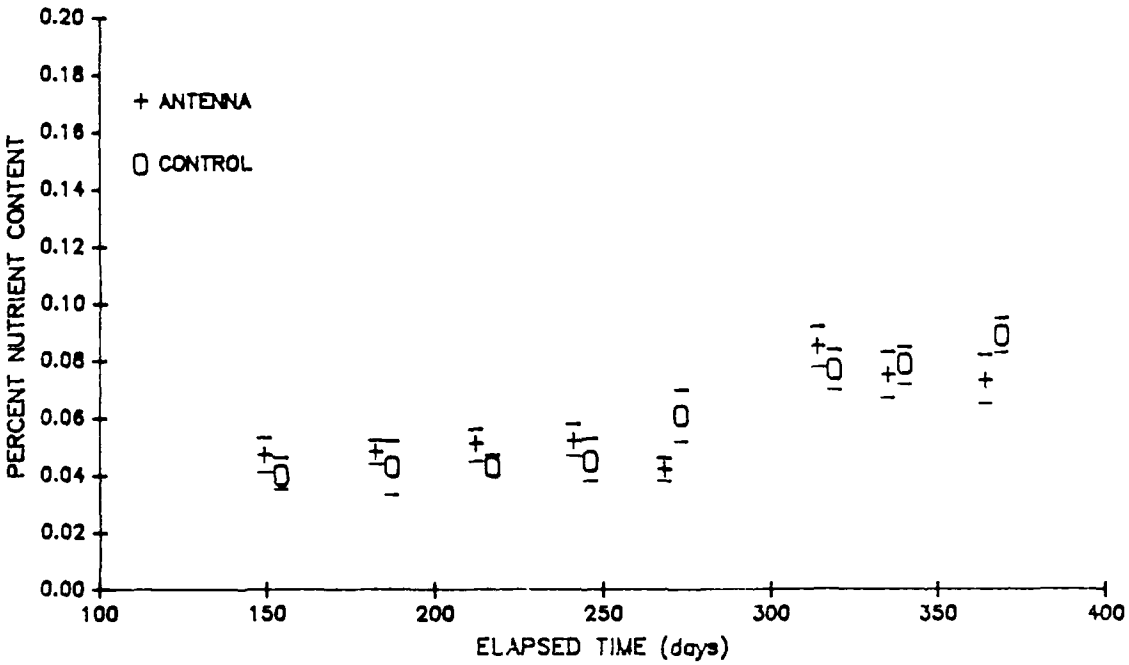

FIGURE 59. Percent phosphorus content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

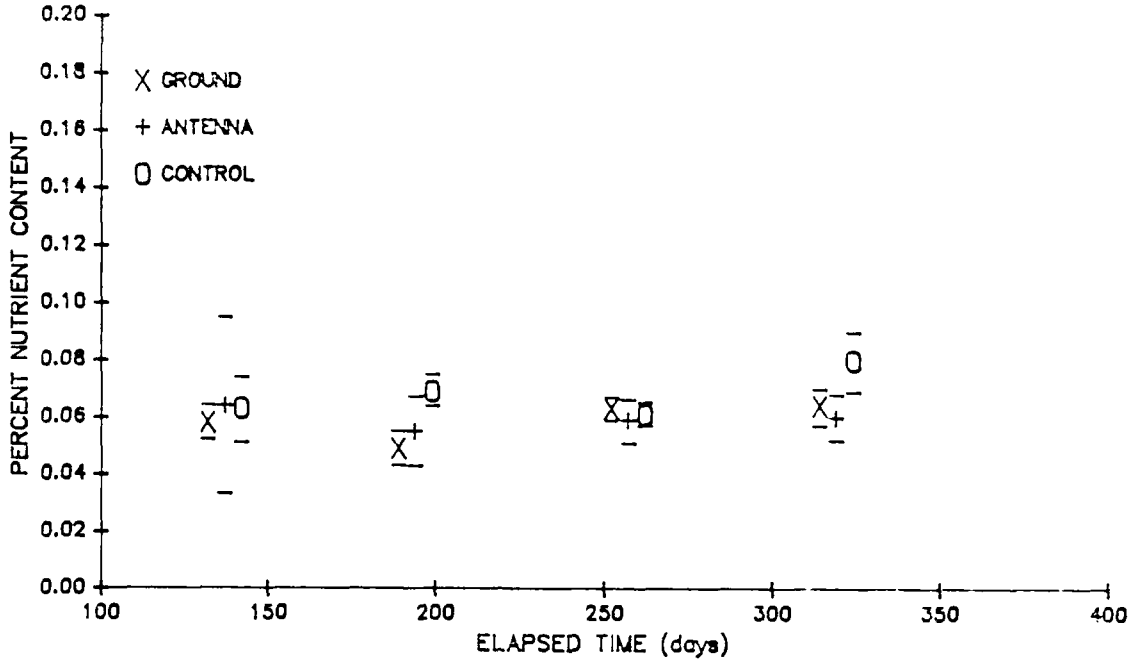

FIGURE 60. Percent phosphorus content of bulk oak leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

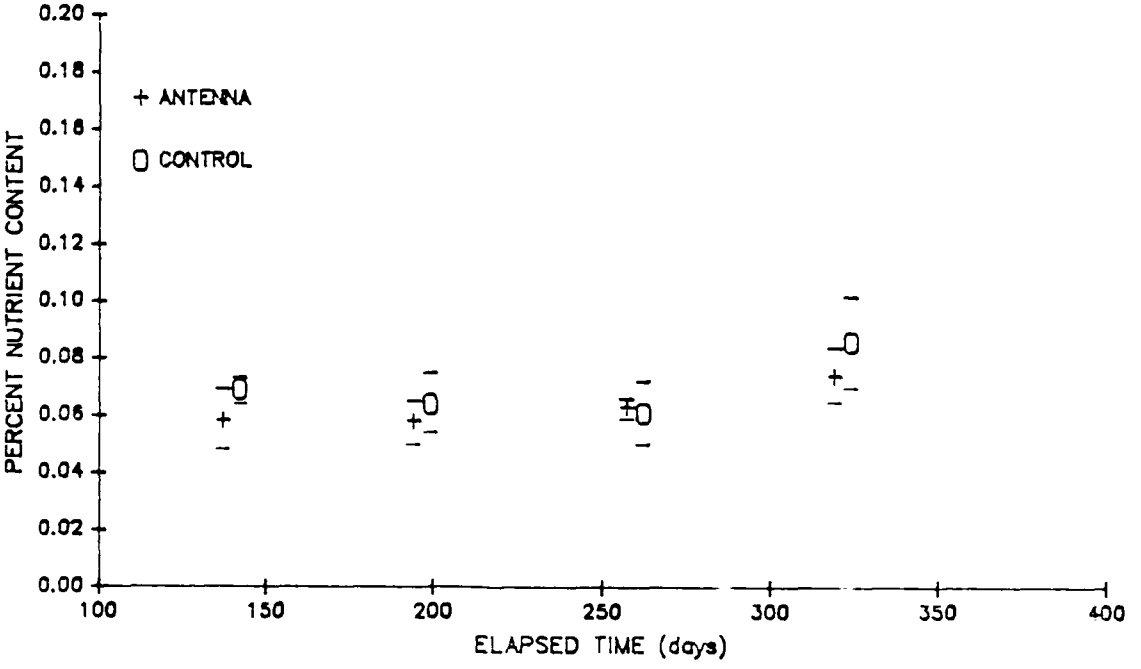

FIGURE 61. Percent phosphorus content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

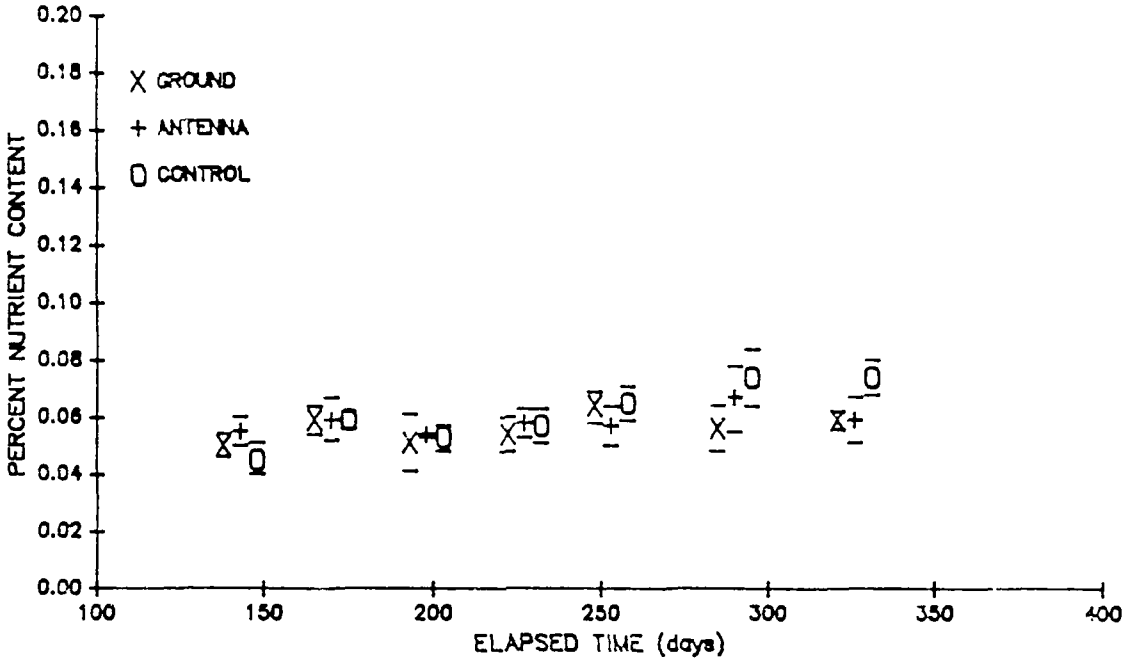

FIGURE 62. Percent phosphorus content of bulk oak leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

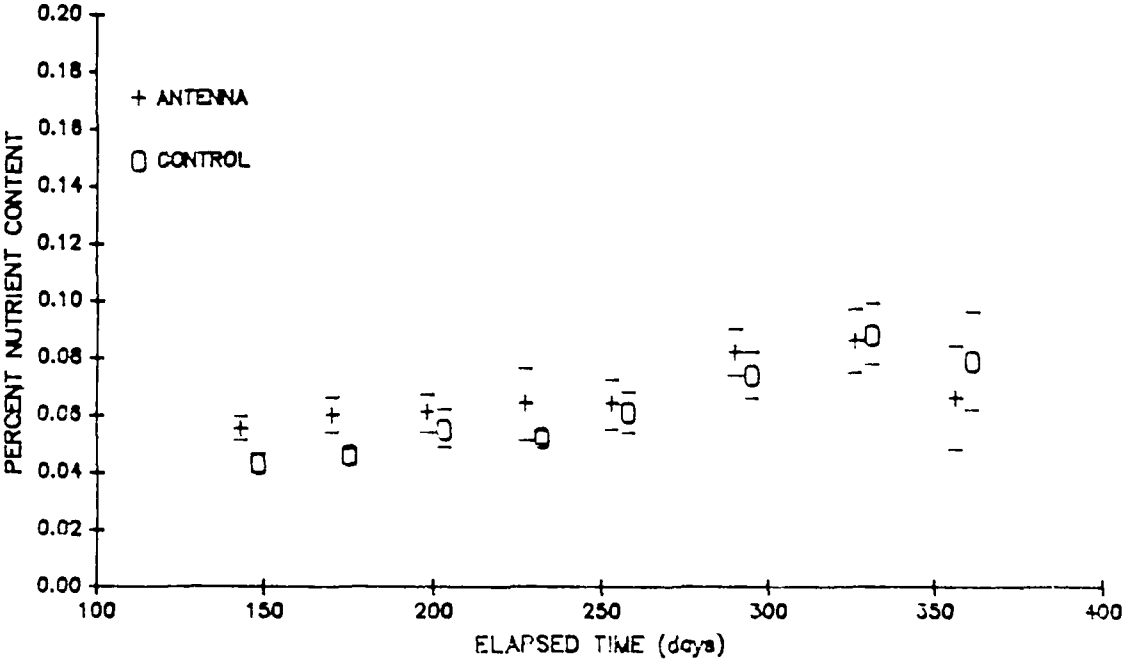

FIGURE 63. Percent phosphorus content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

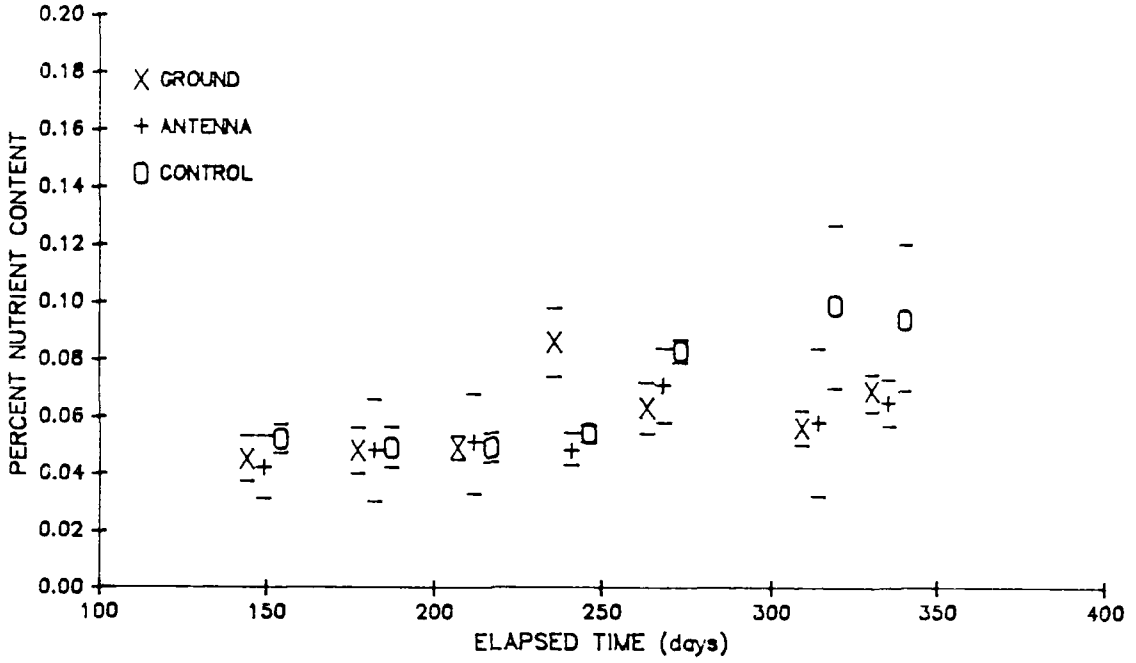

FIGURE 64. Percent phosphorus content of bulk oak leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

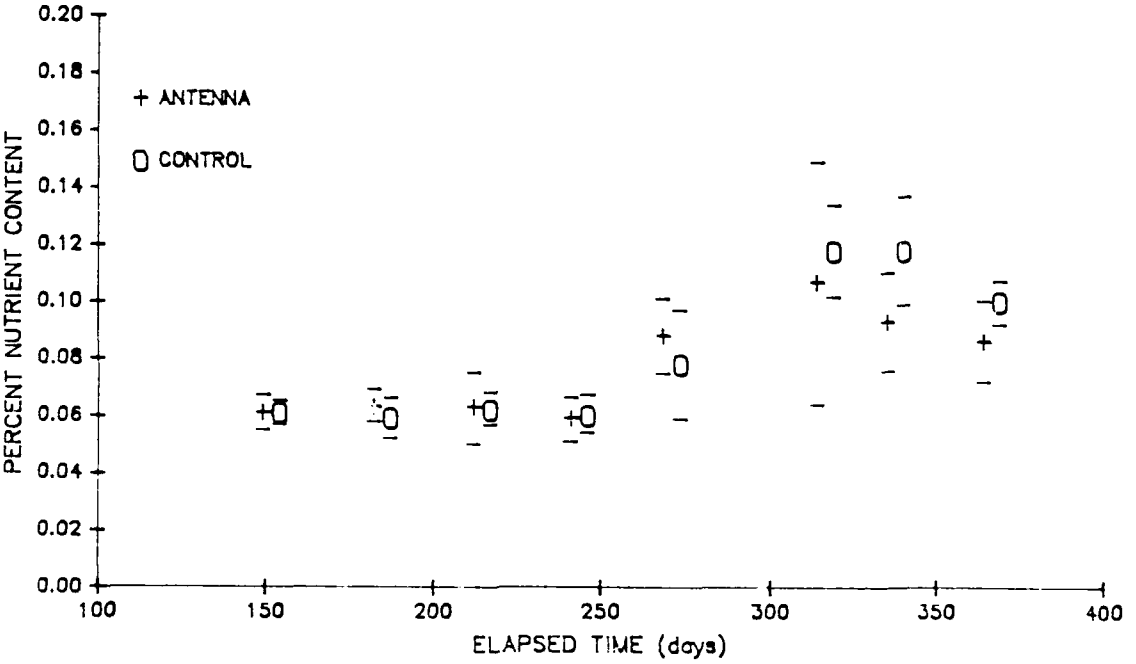

FIGURE 65. Percent phosphorus content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

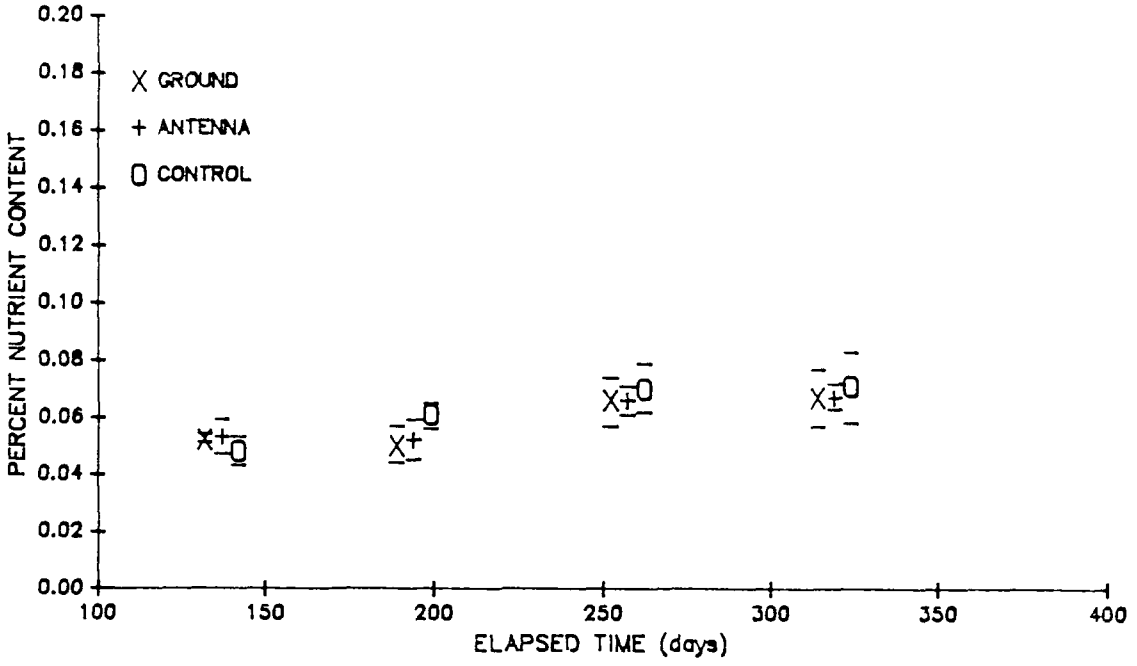

FIGURE 66. Percent phosphorus content of bulk maple leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

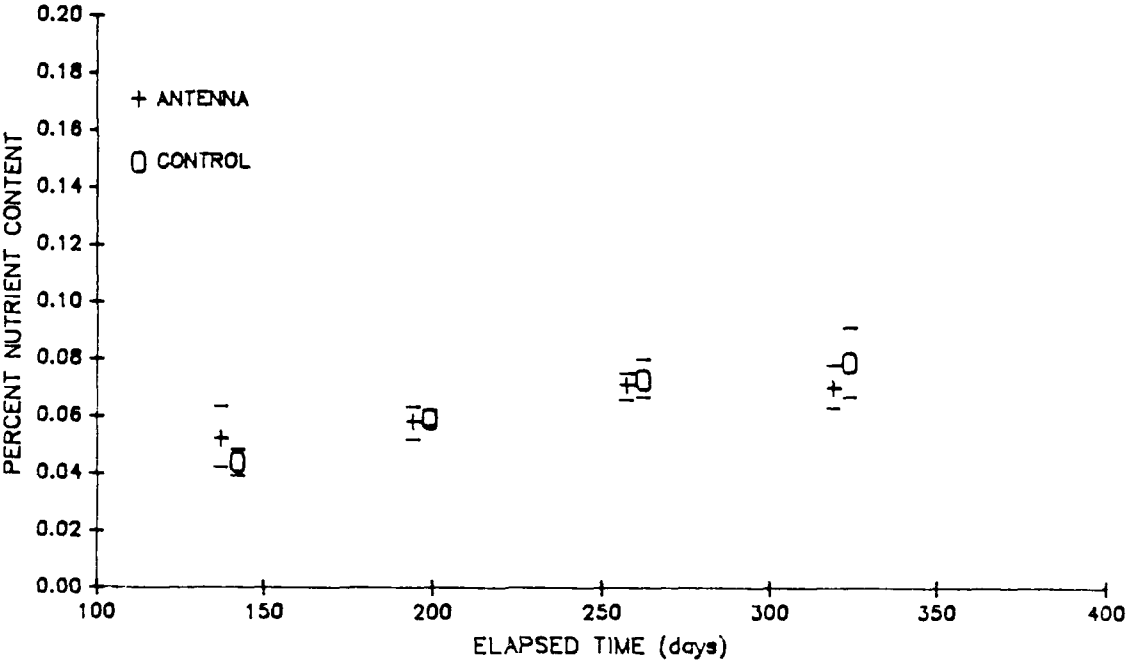

FIGURE 67. Percent phosphorus content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

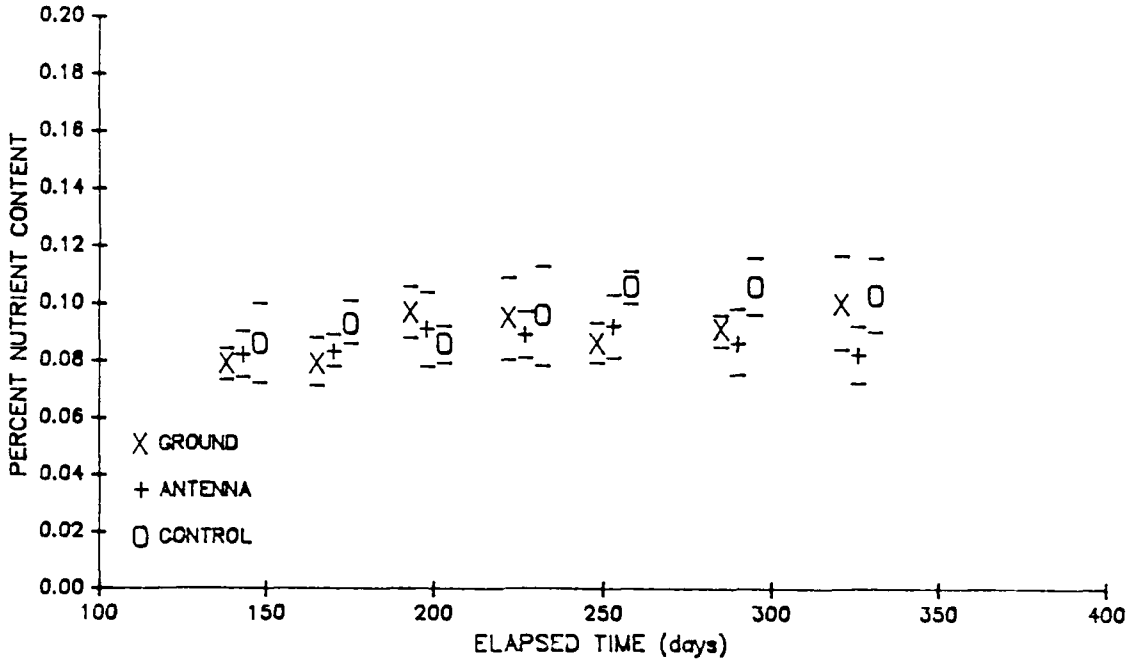

FIGURE 68. Percent phosphorus content of bulk maple leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

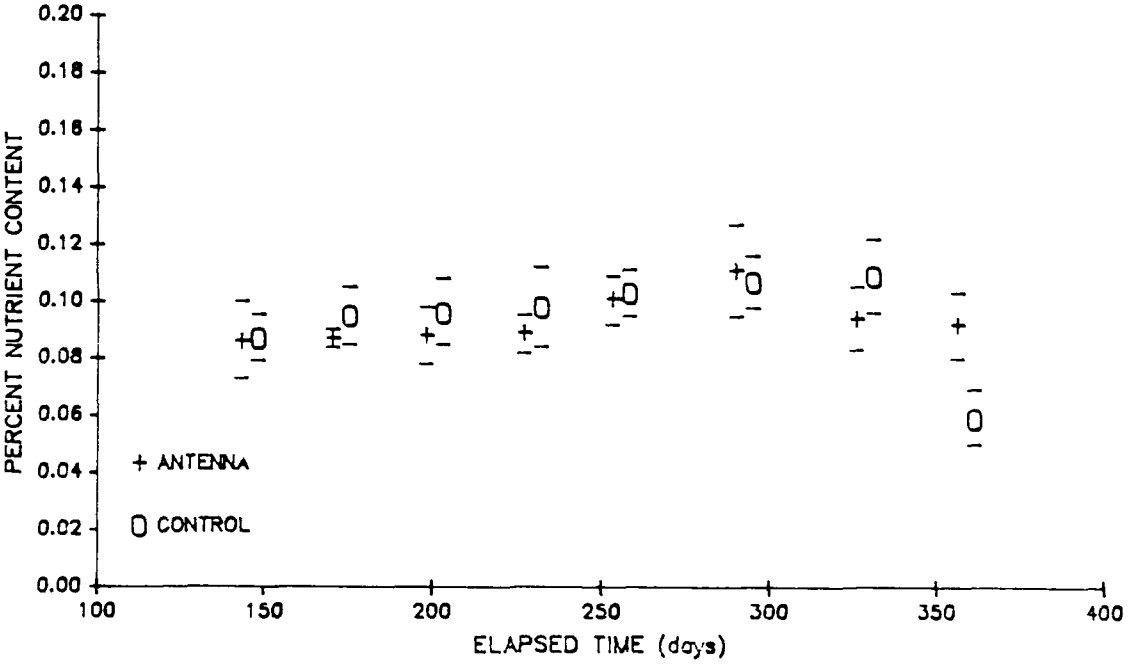

FIGURE 69. Percent phosphorus content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

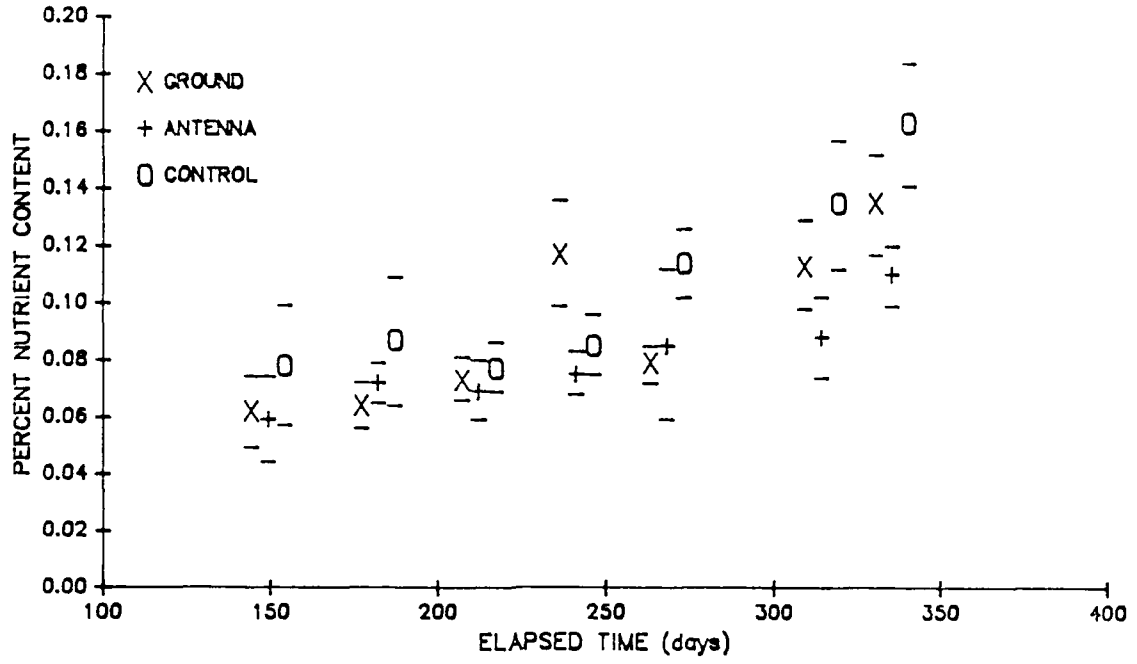

FIGURE 70. Percent phosphorus content of bulk maple leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

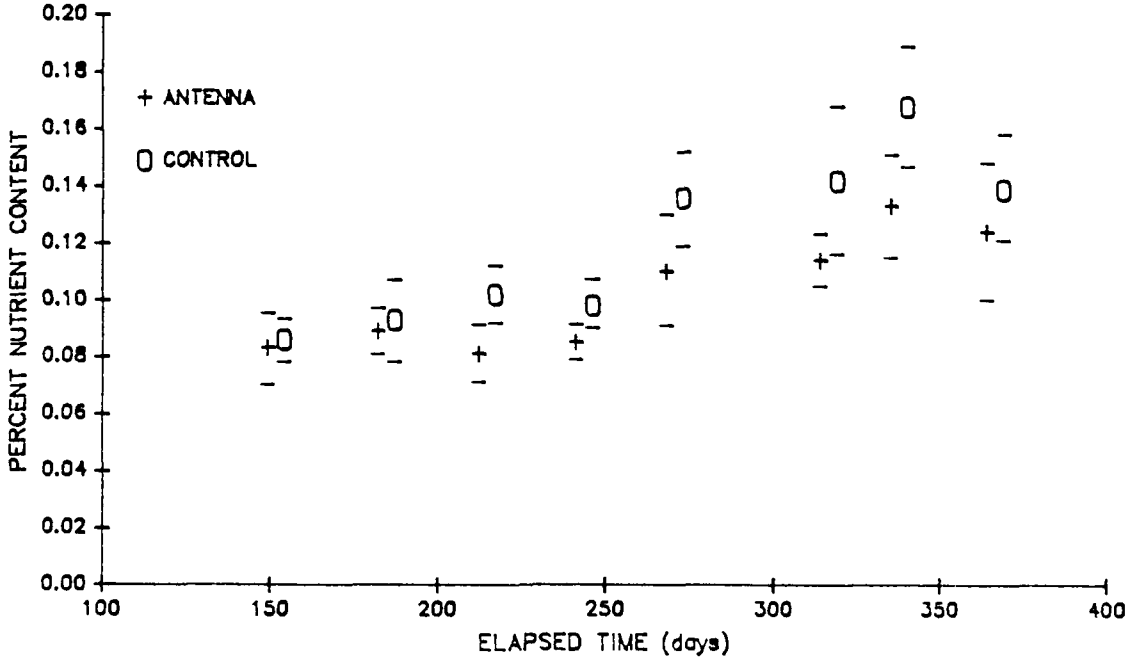

FIGURE 71. Percent phosphorus content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

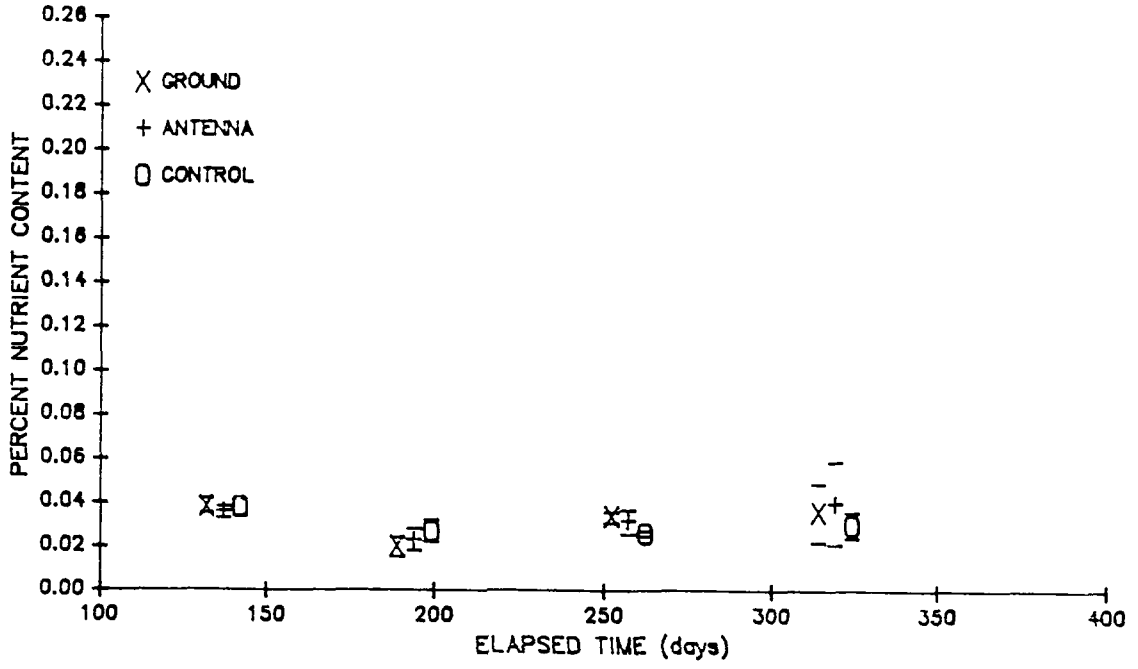

FIGURE 72. Percent potassium content of bulk pine needle samples retrieved from the three plantation subunits during the 1986–1987 experiment.

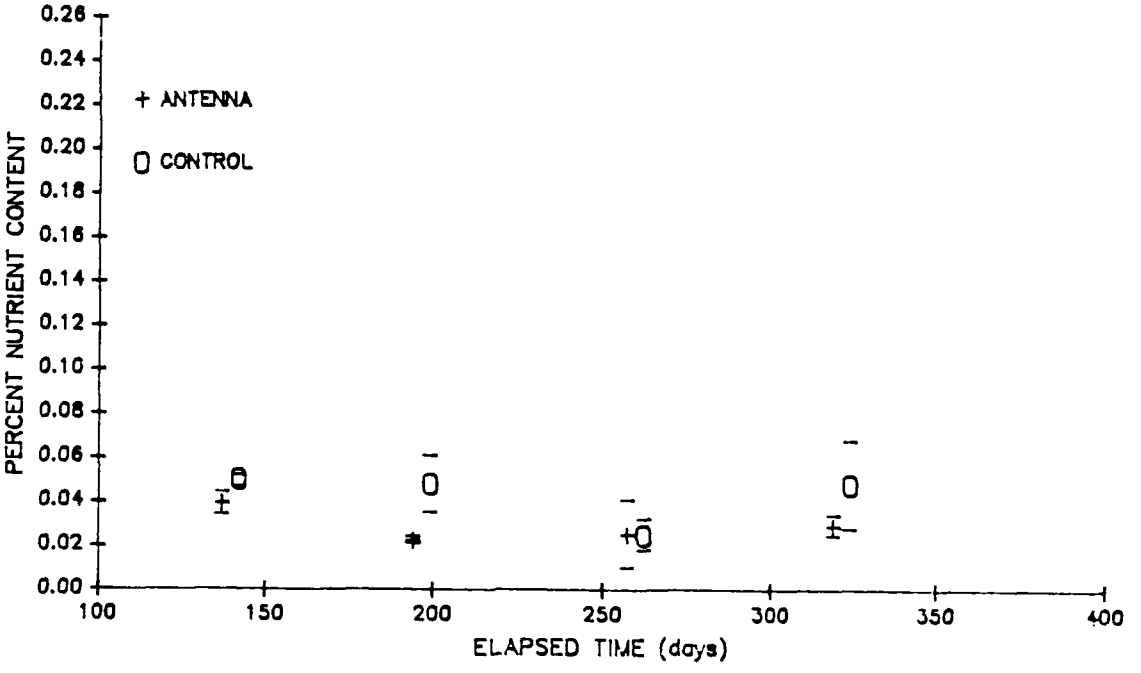

FIGURE 73. Percent potassium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

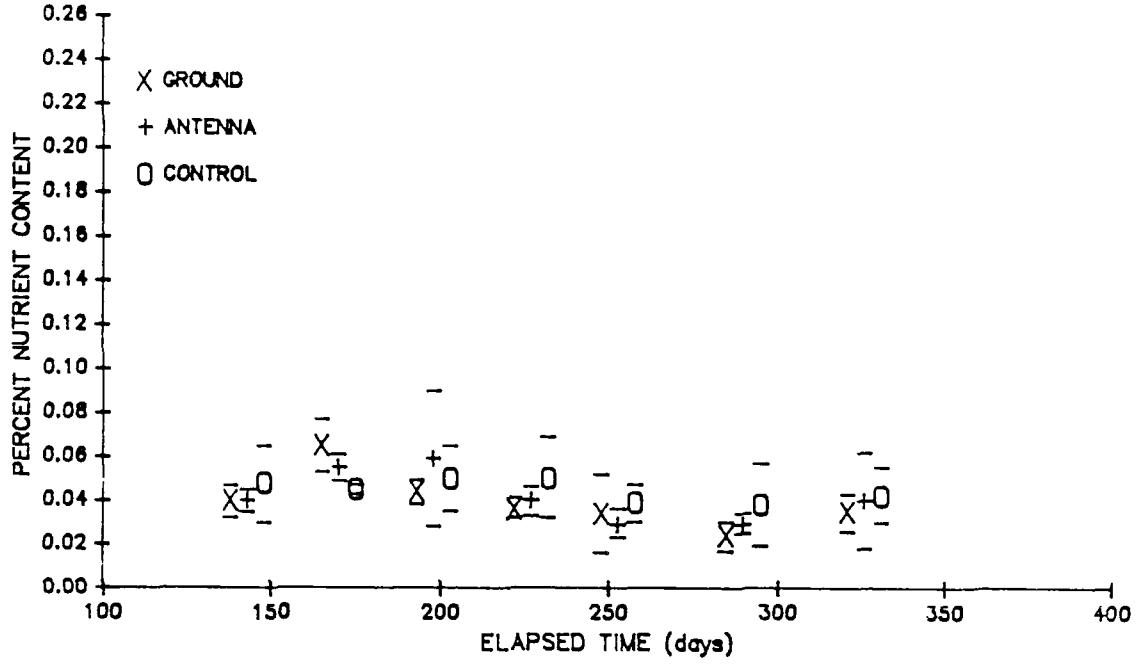

FIGURE 74. Percent potassium content of bulk pine needle samples retrieved from the three plantation subunits during the 1985–1986 experiment.

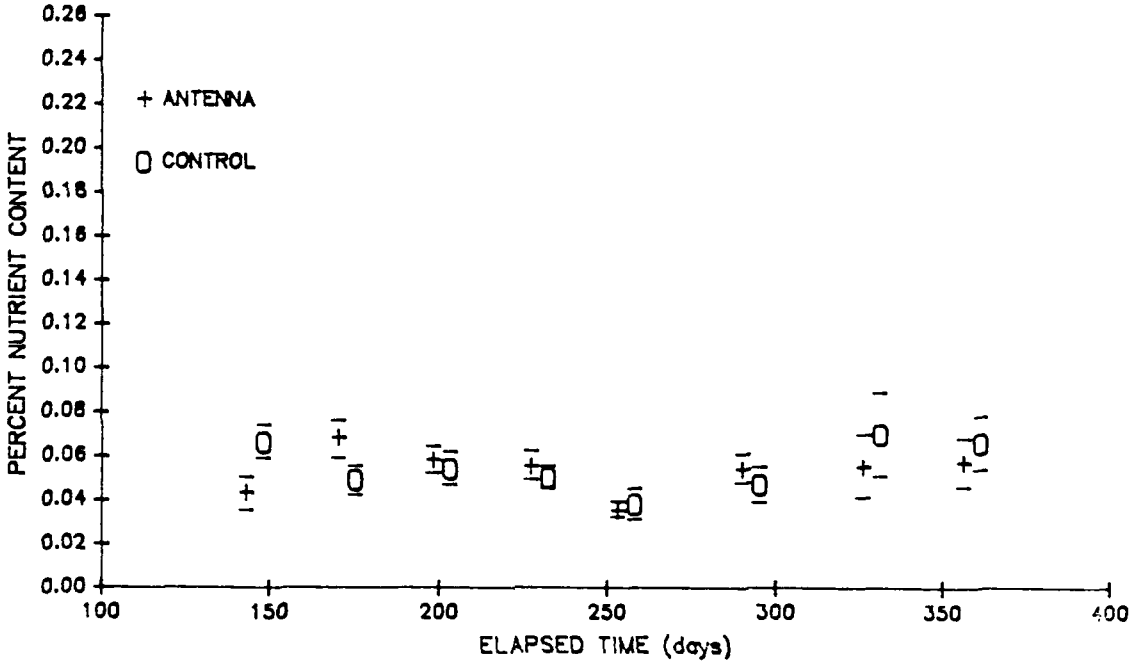

FIGURE 75. Percent potassium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

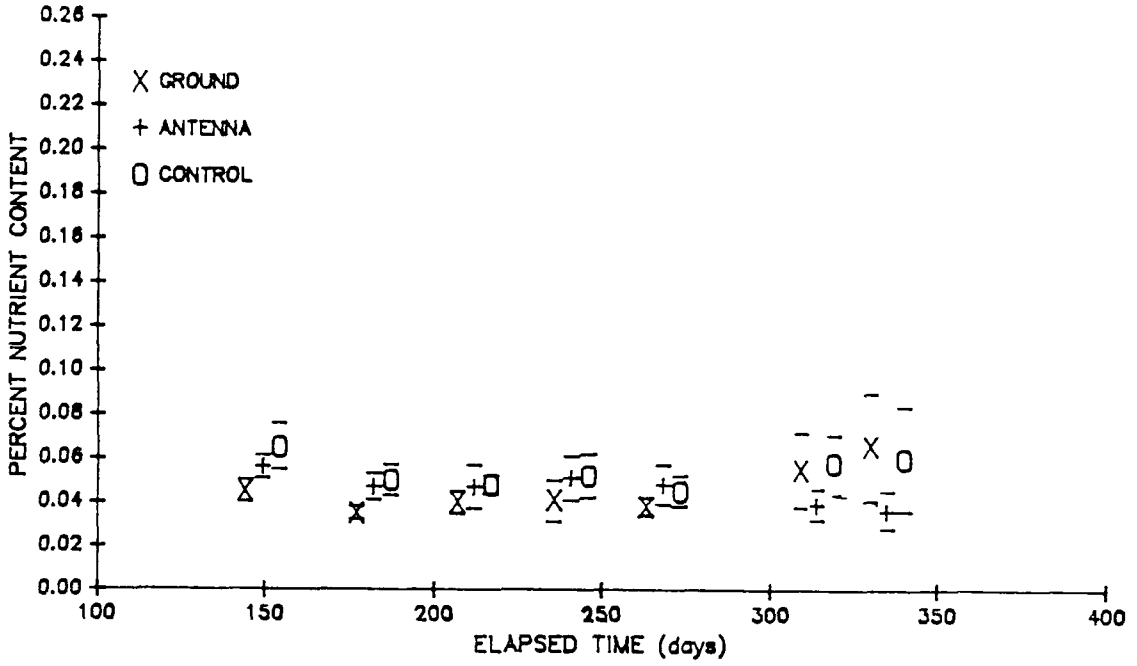

FIGURE 76. Percent potassium content of bulk pine needle samples retrieved from the three plantation subunits during the 1984–1985 experiment.

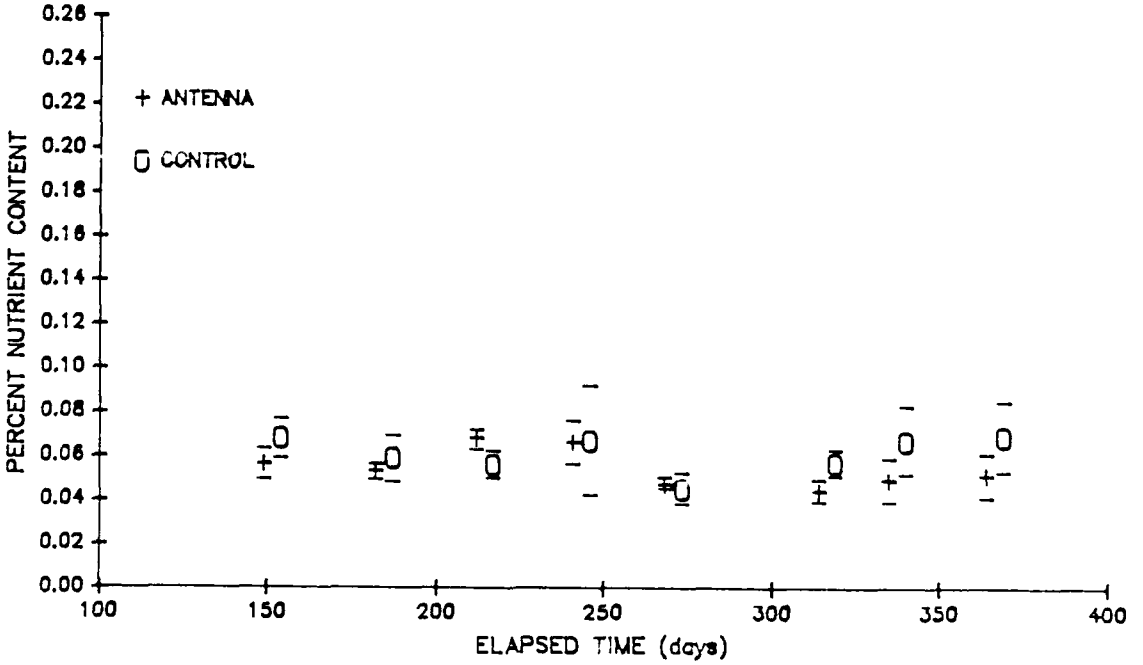

FIGURE 77. Percent potassium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

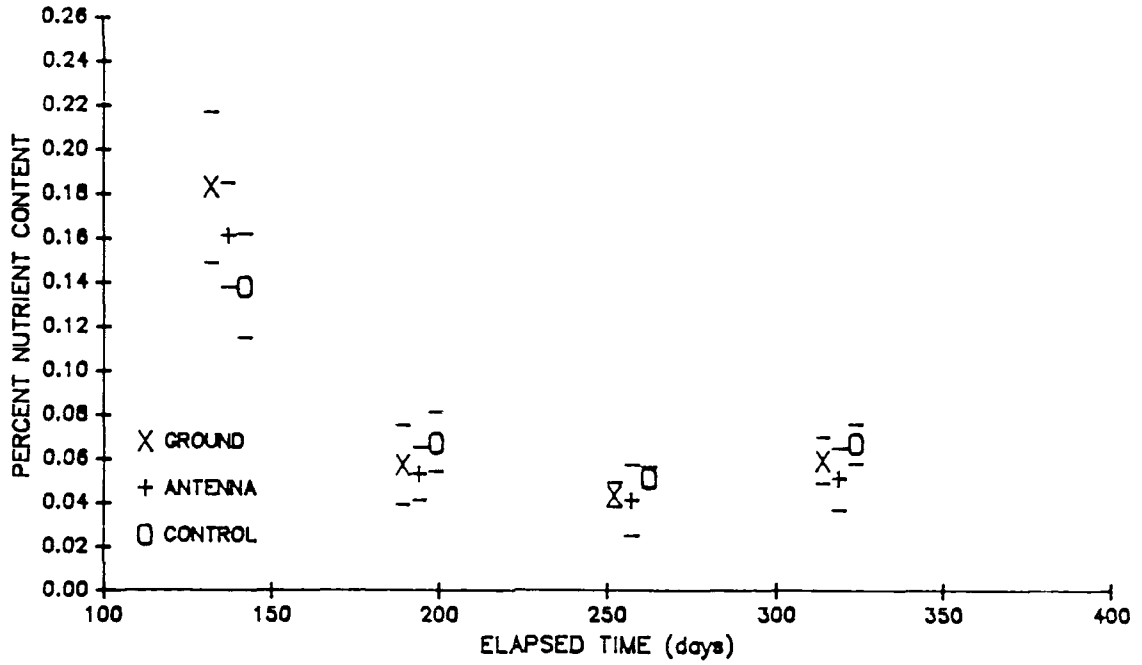

FIGURE 78. Percent potassium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

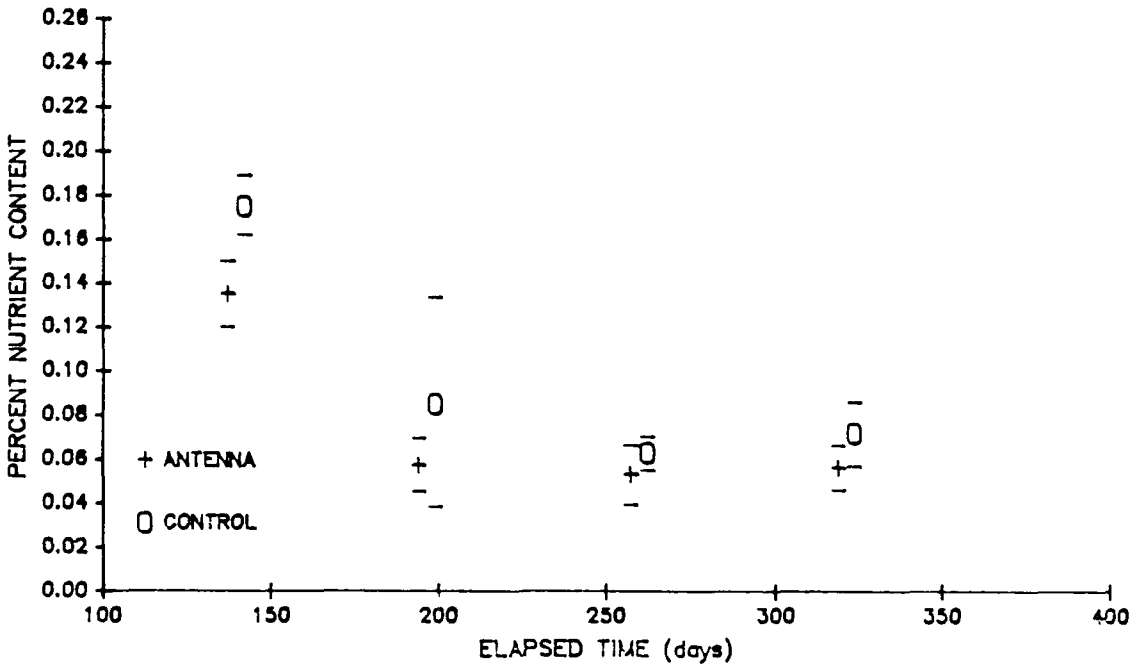

FIGURE 79. Percent potassium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

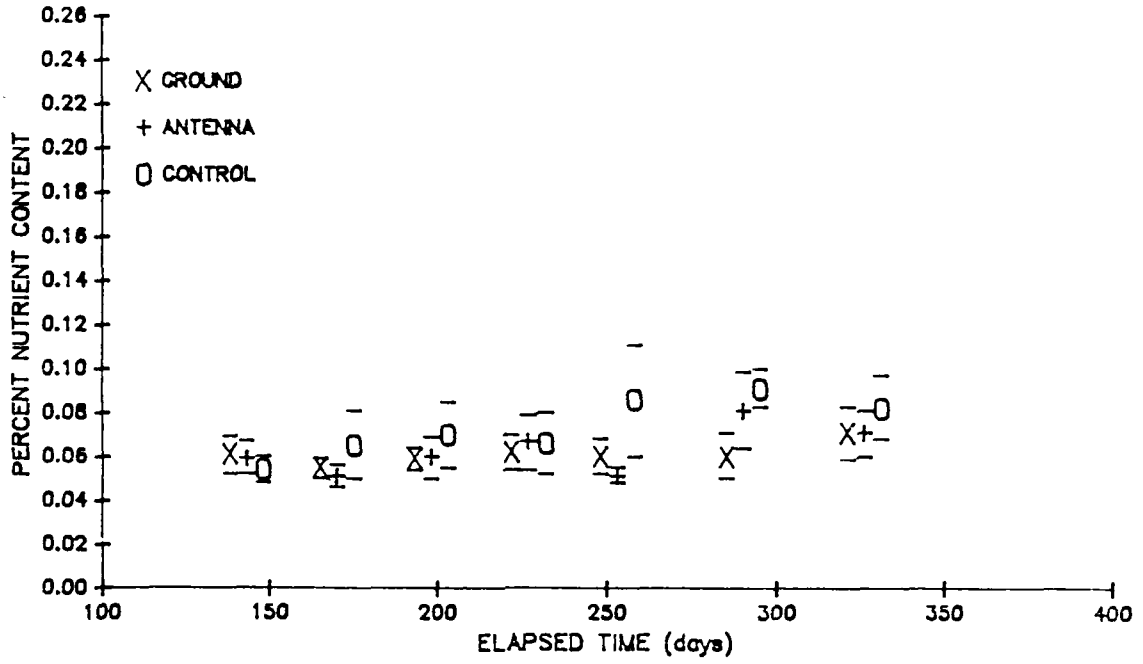

FIGURE 80. Percent potassium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

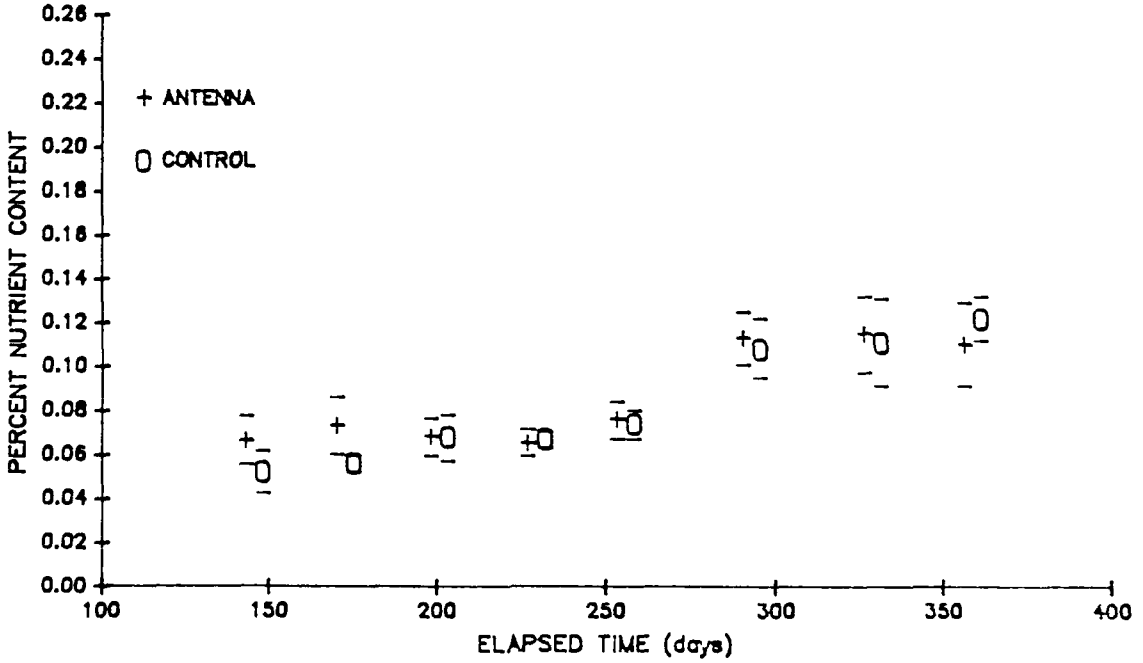

FIGURE 81. Percent potassium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

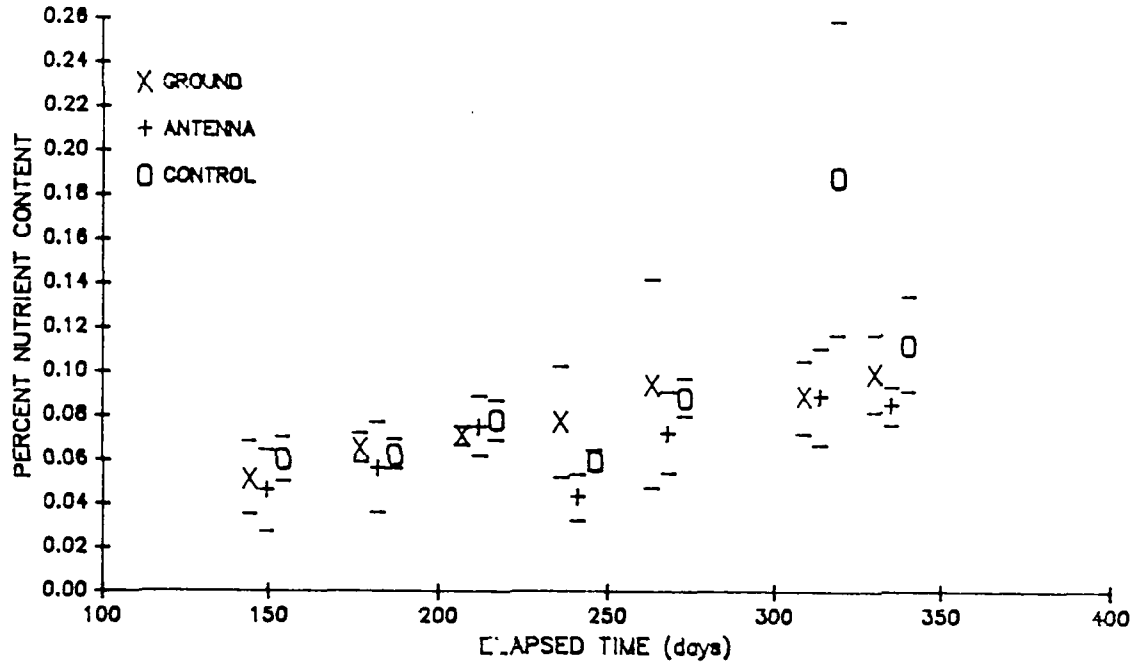

FIGURE 82. Percent potassium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

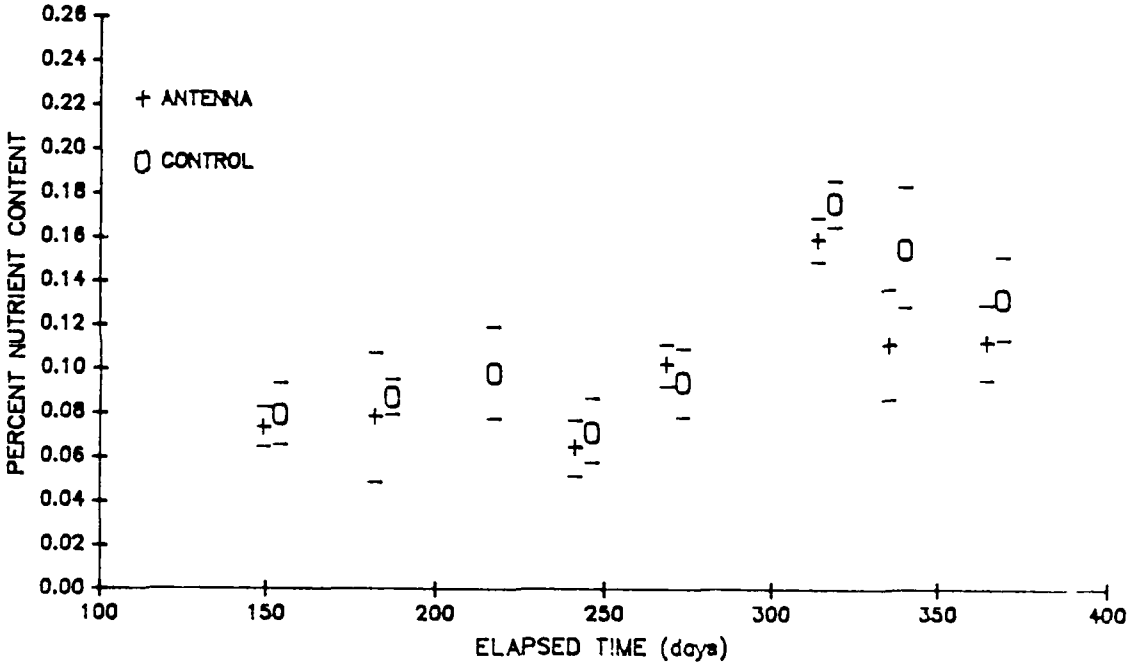

FIGURE 83. Percent potassium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

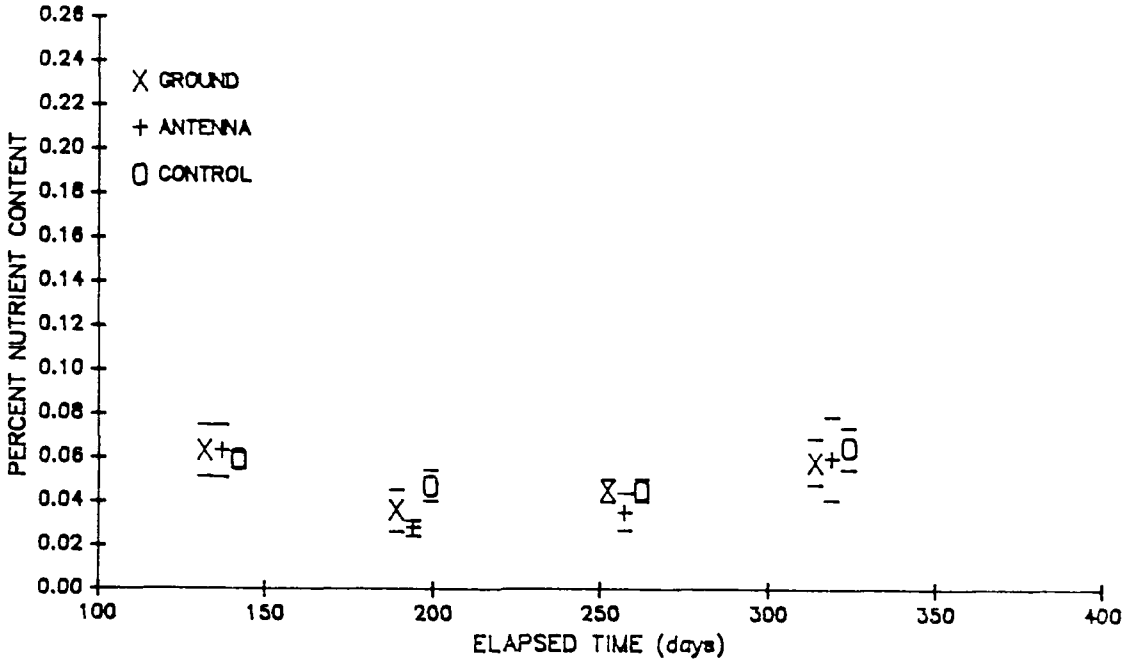

FIGURE 84. Percent potassium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

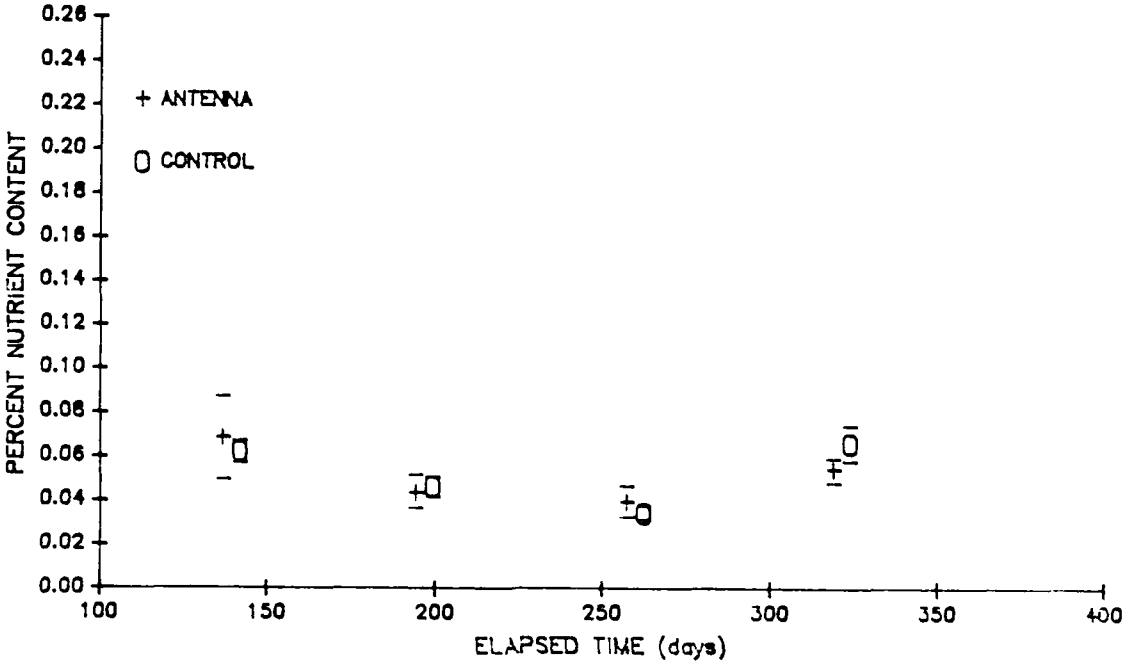

FIGURE 85. Percent potassium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

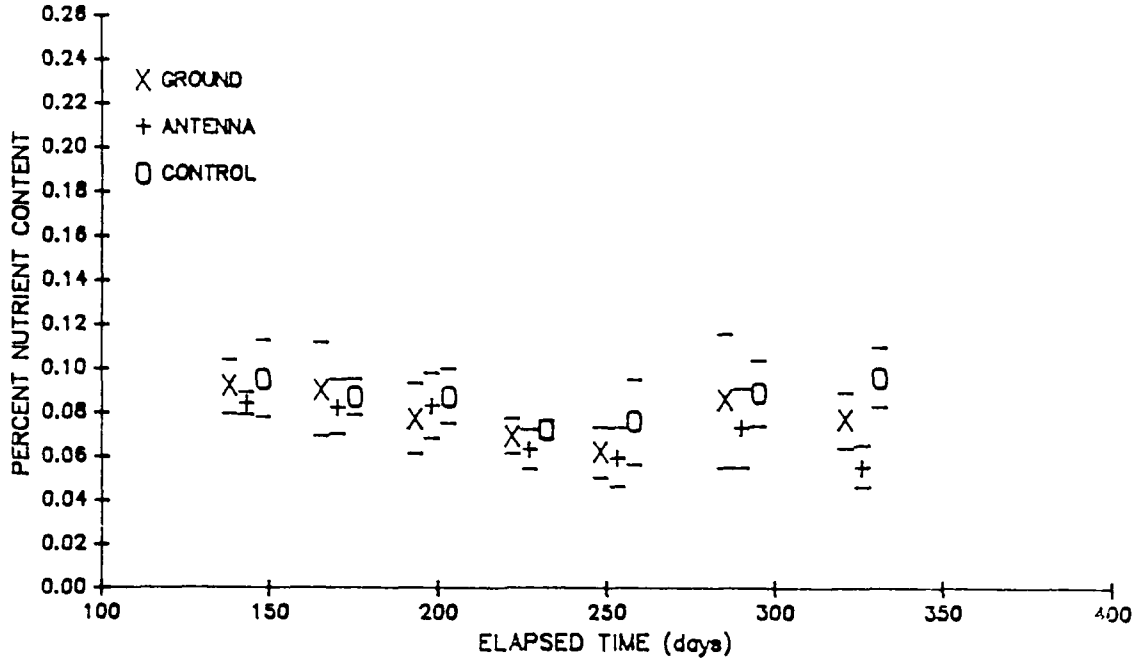

FIGURE 86. Percent potassium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

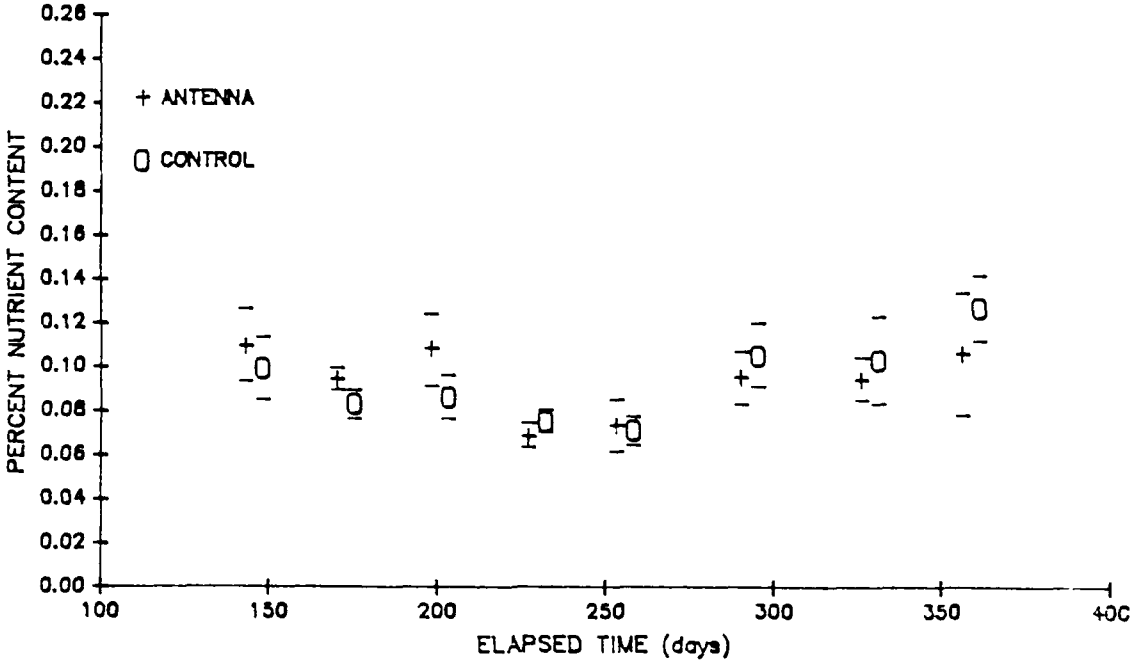

FIGURE 87. Percent potassium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

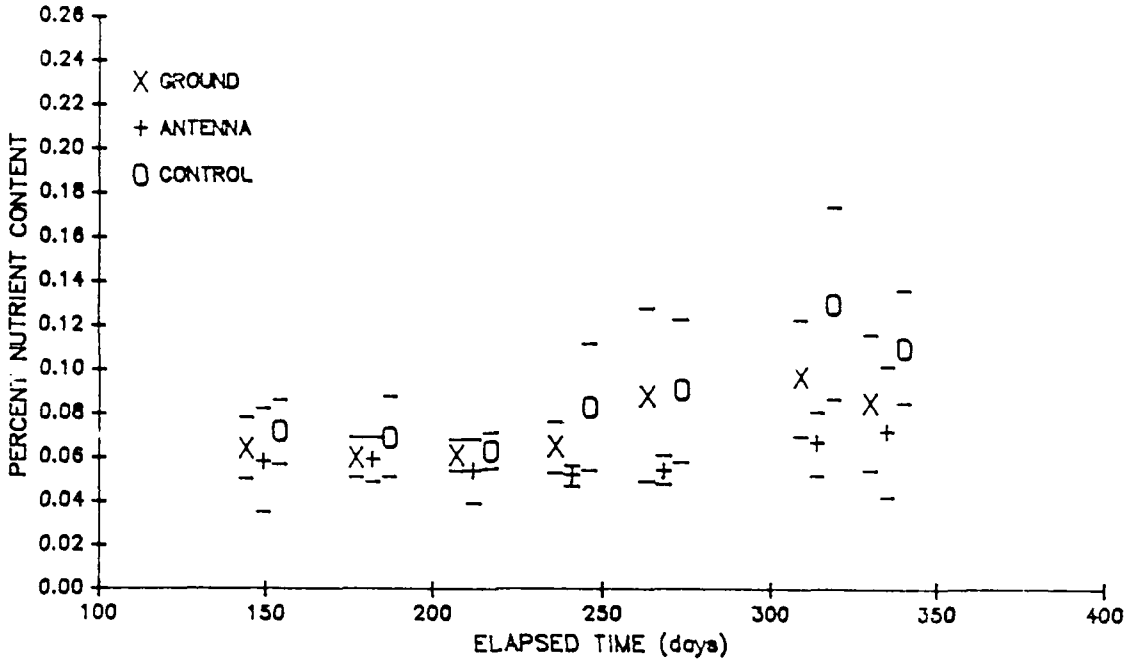

FIGURE 88. Percent potassium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

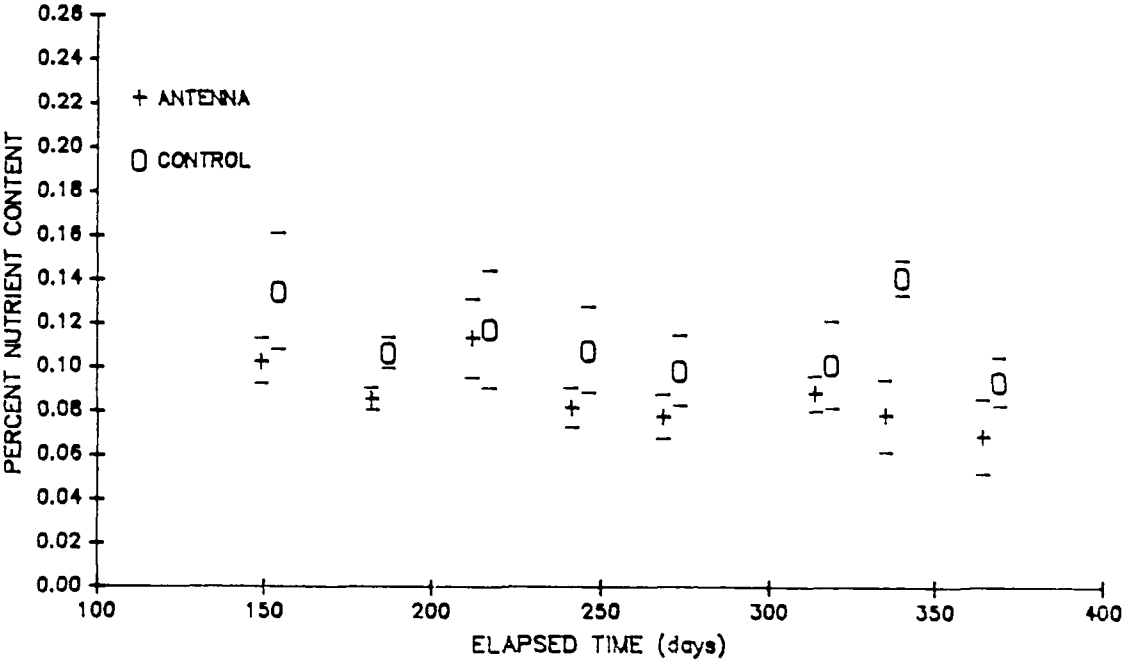

FIGURE 89. Percent potassium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

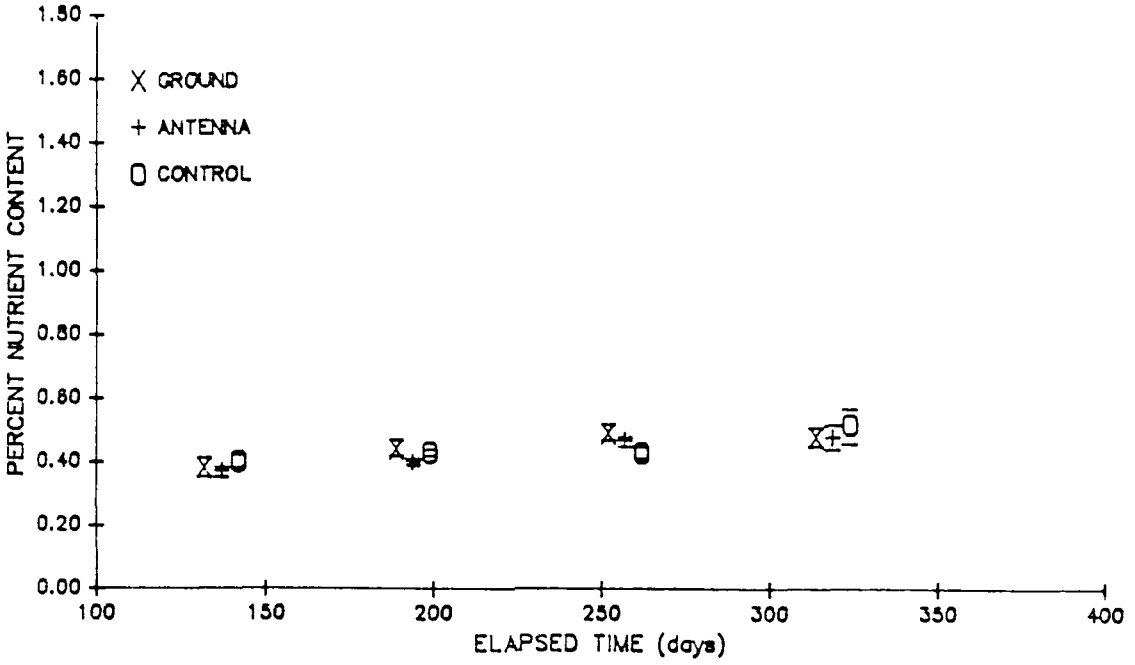

FIGURE 90. Percent calcium content of bulk pine needle samples retrieved from the three plantation subunits during the 1986-1987 experiment.

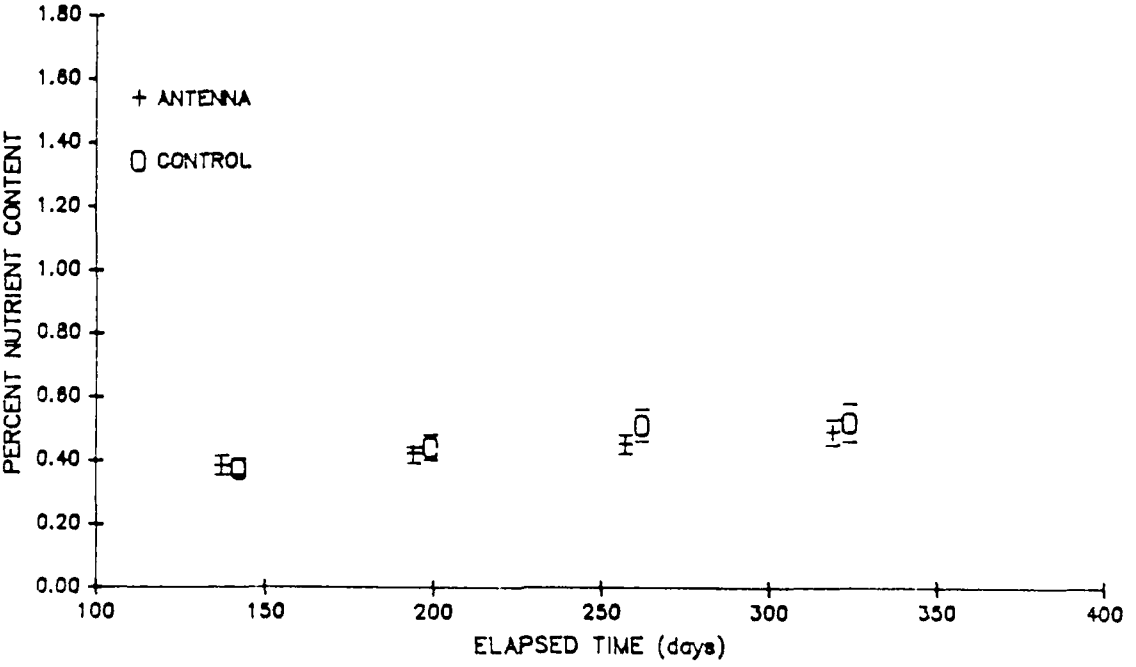

FIGURE 91. Percent calcium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1986-1987 experiment.

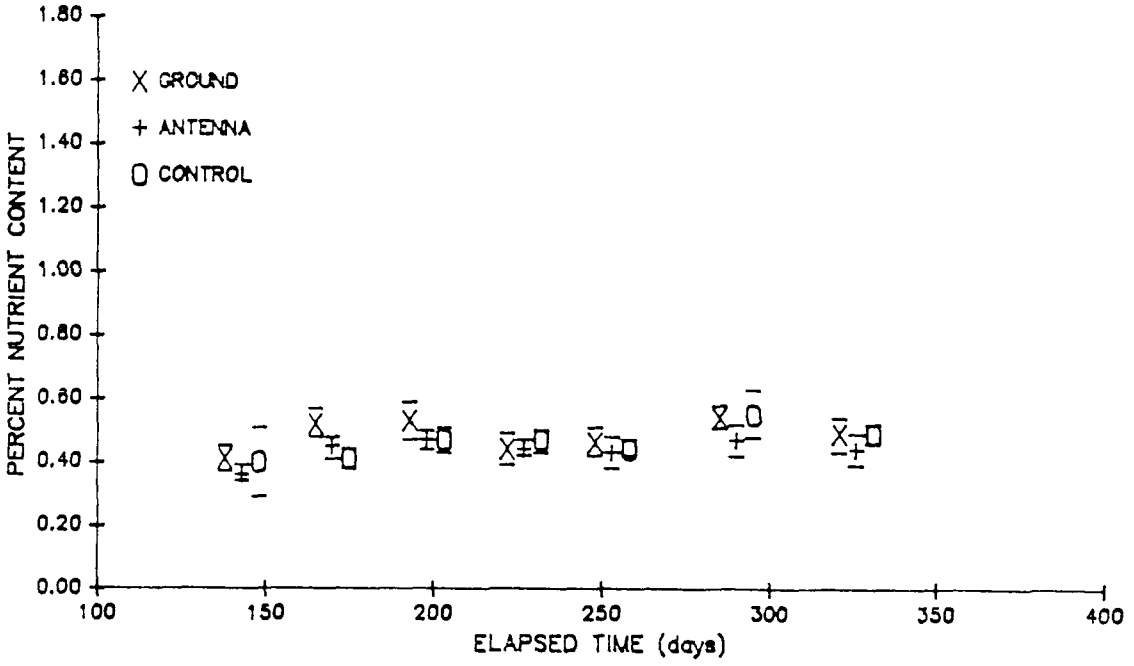

FIGURE 92. Percent calcium content of bulk pine needle samples retrieved from the three plantation subunits during the 1985–1986 experiment.

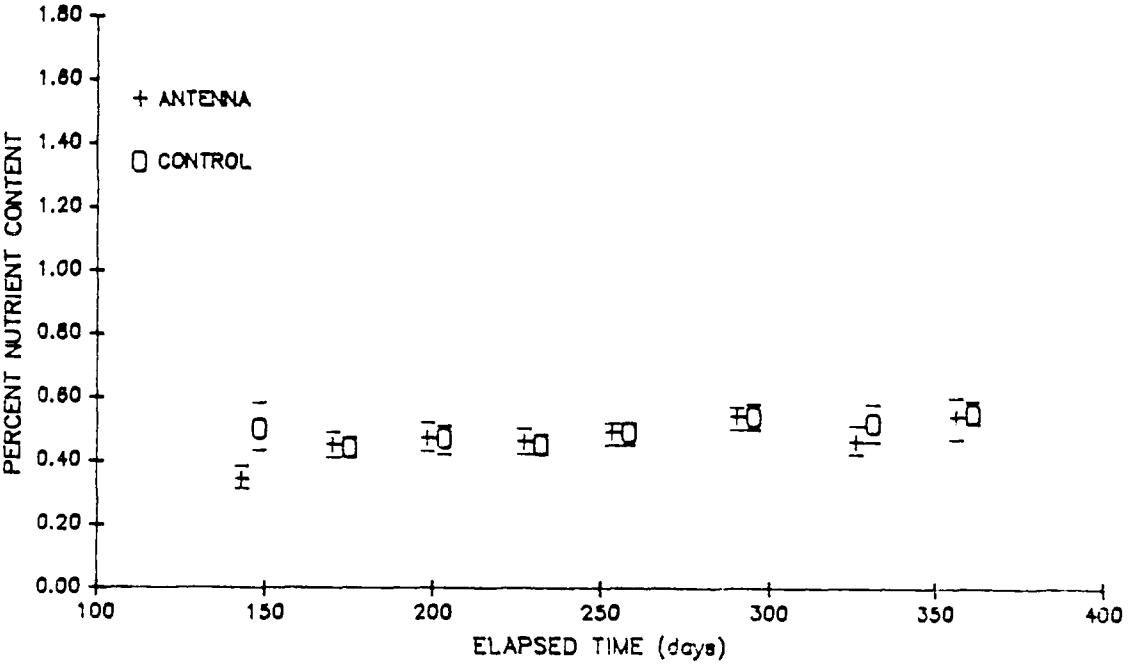

FIGURE 93. Percent calcium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

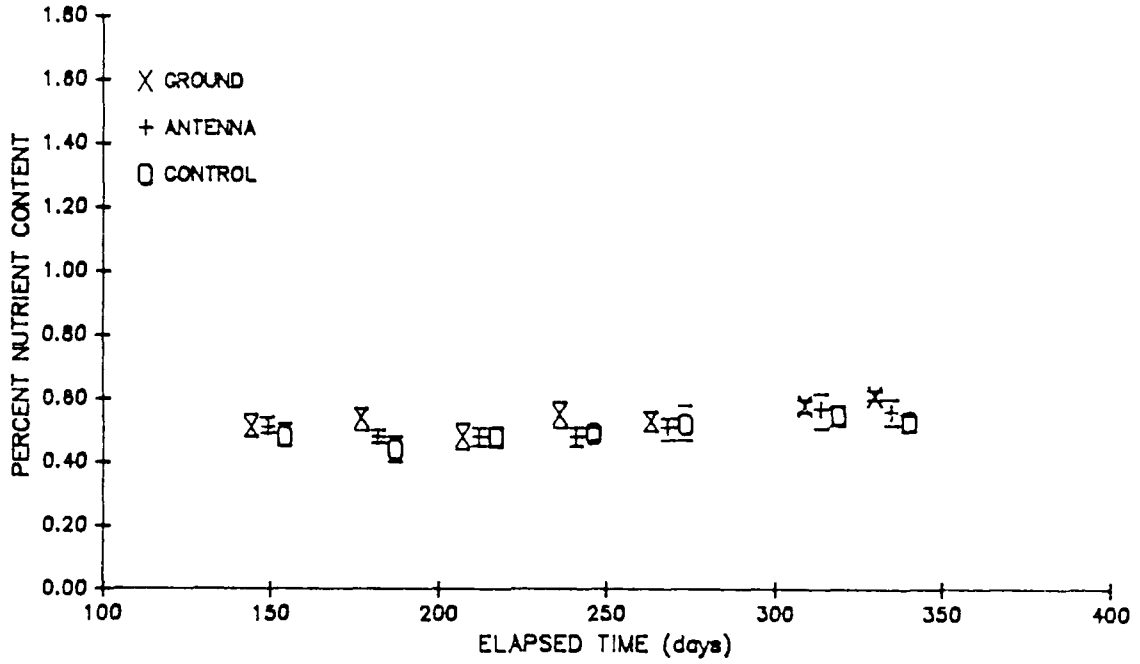

FIGURE 94. Percent calcium content of bulk pine needle samples retrieved from the three plantation subunits during the 1984–1985 experiment.

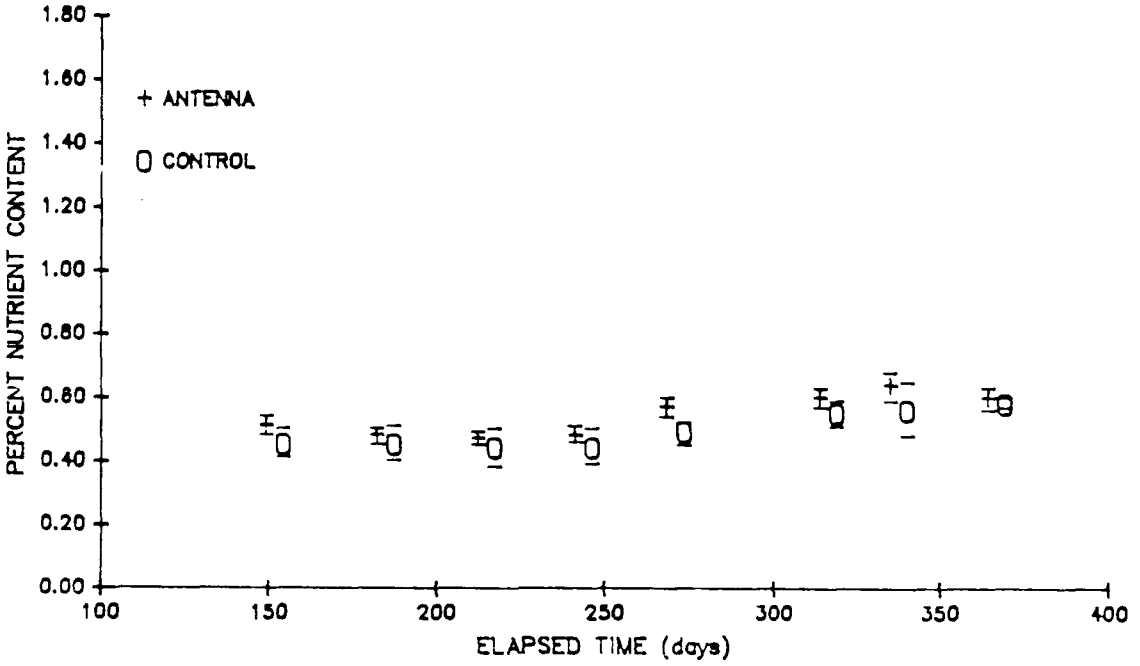

FIGURE 95 Percent calcium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

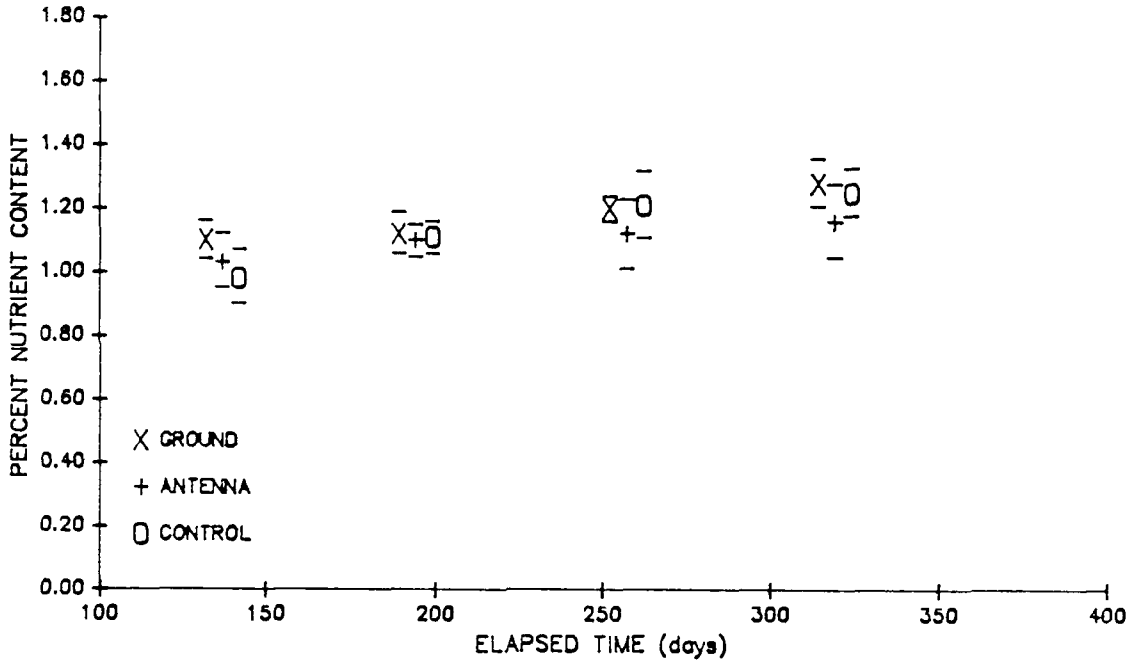

FIGURE 96. Percent calcium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

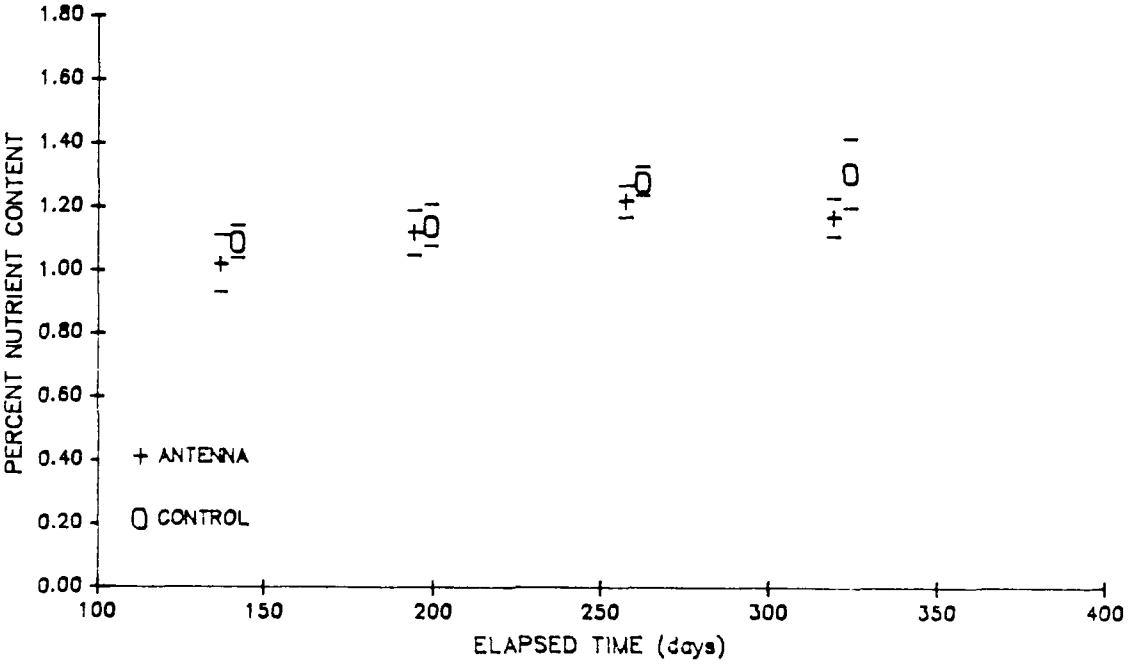

FIGURE 97. Percent calcium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

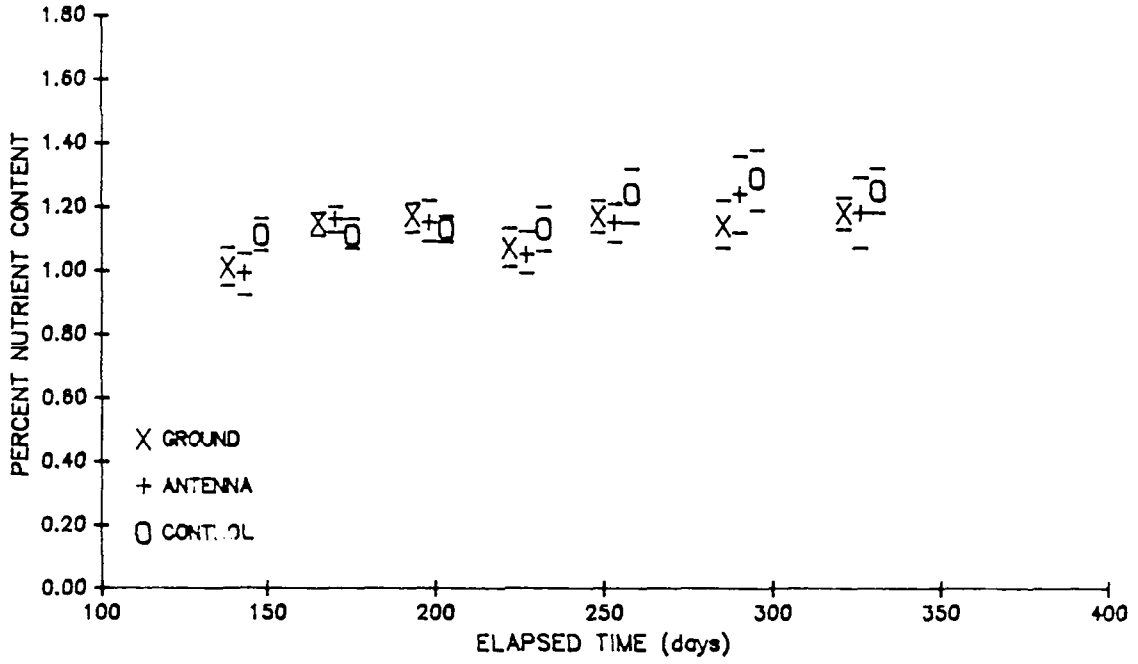

FIGURE 98. Percent calcium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

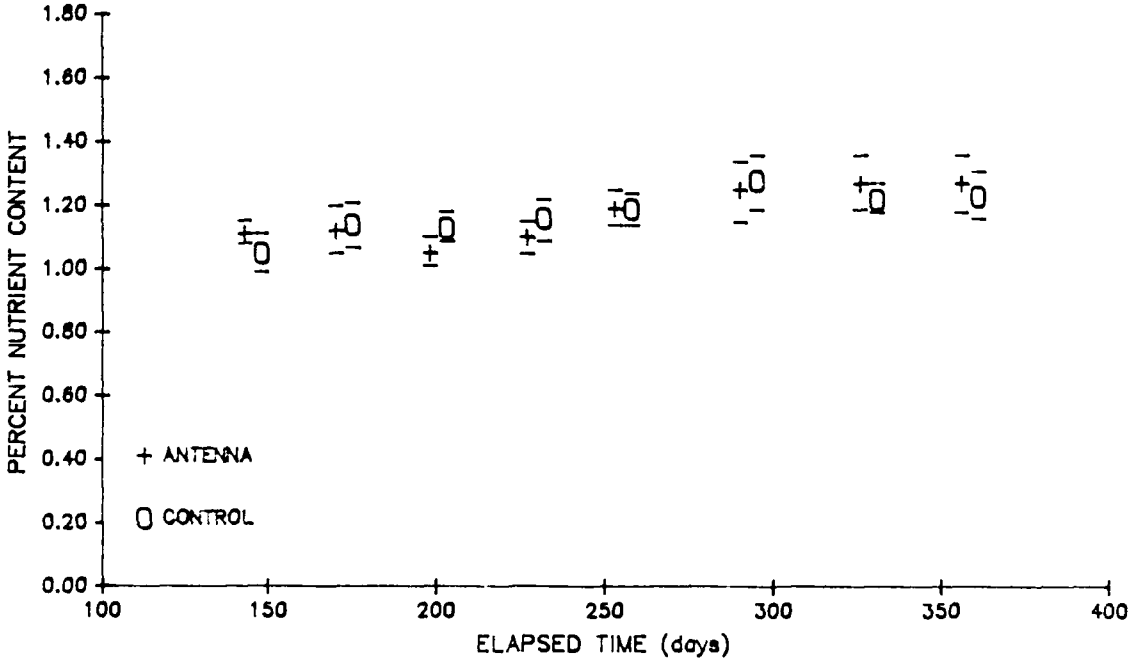

FIGURE 99. Percent calcium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

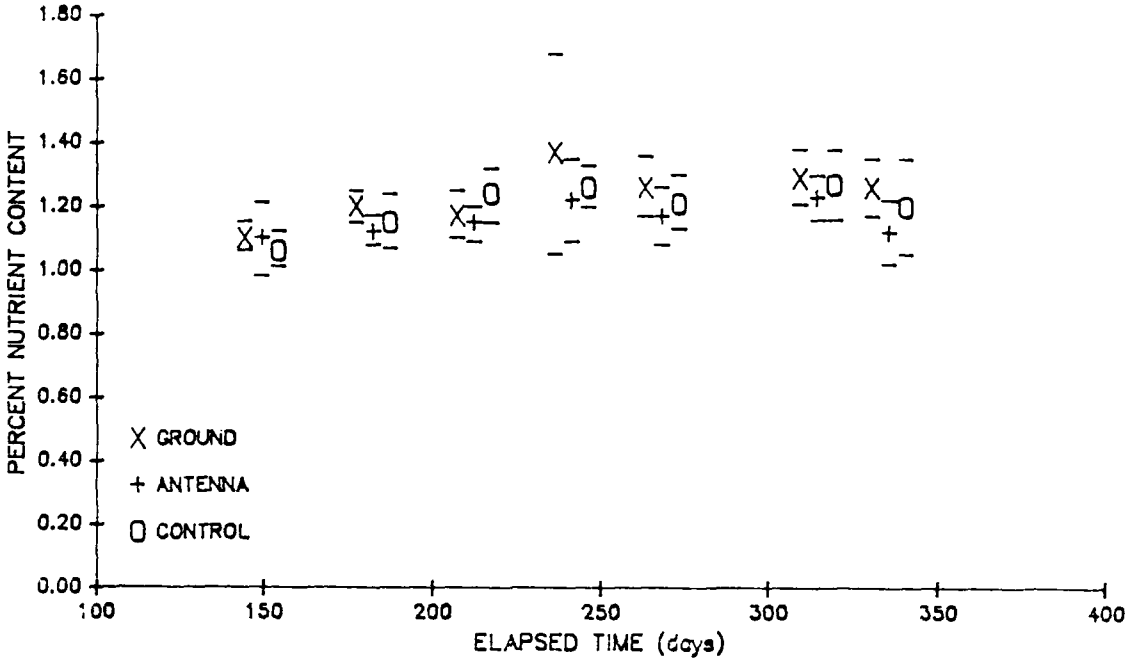

FIGURE 100. Percent calcium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

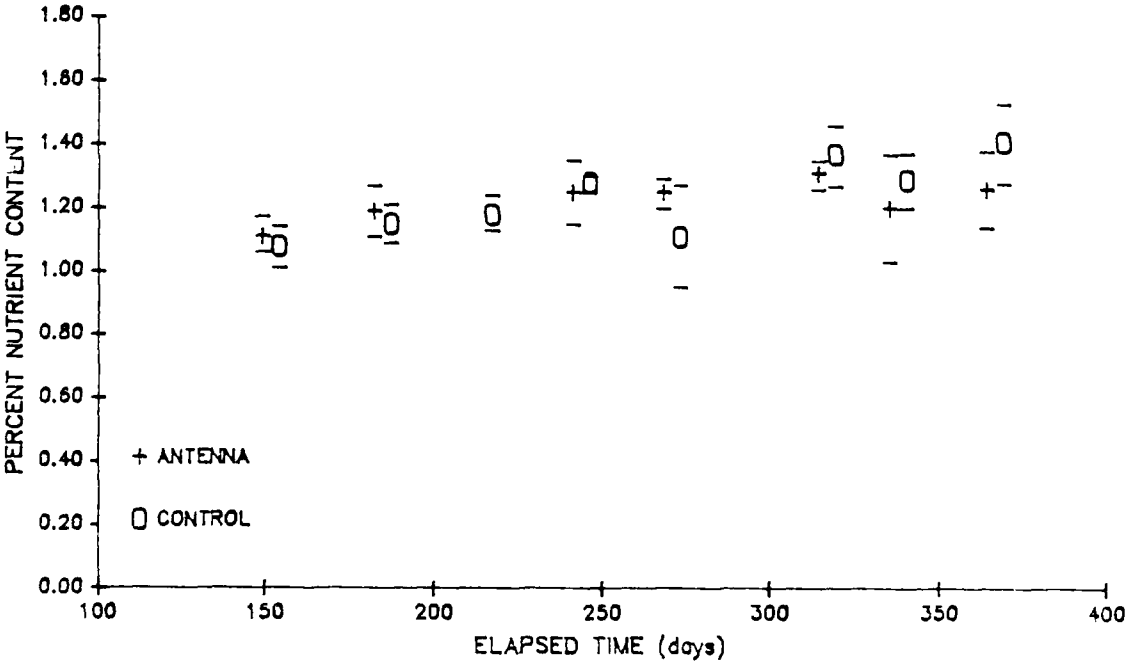

FIGURE 101. Percent calcium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

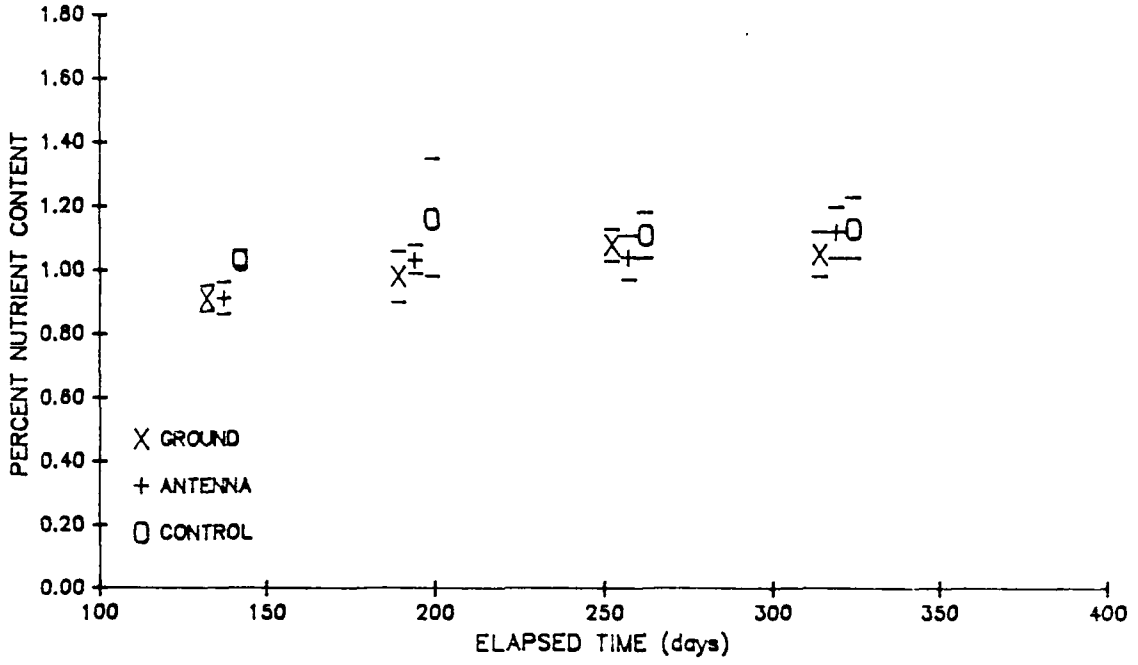

FIGURE 102. Percent calcium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

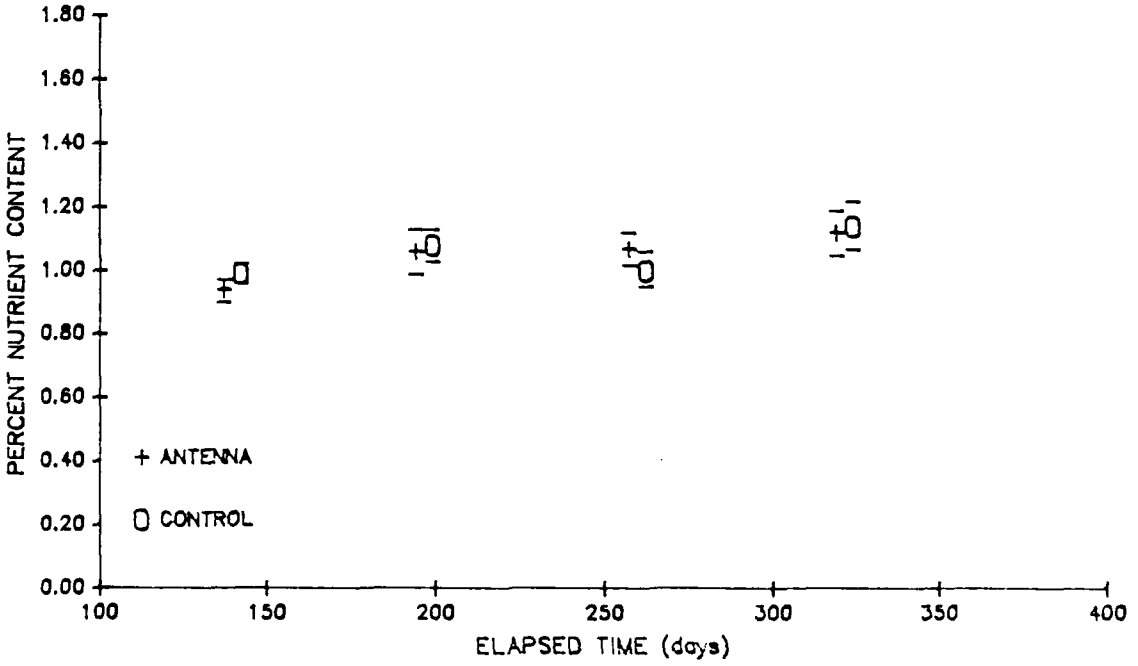

FIGURE 103. Percent calcium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

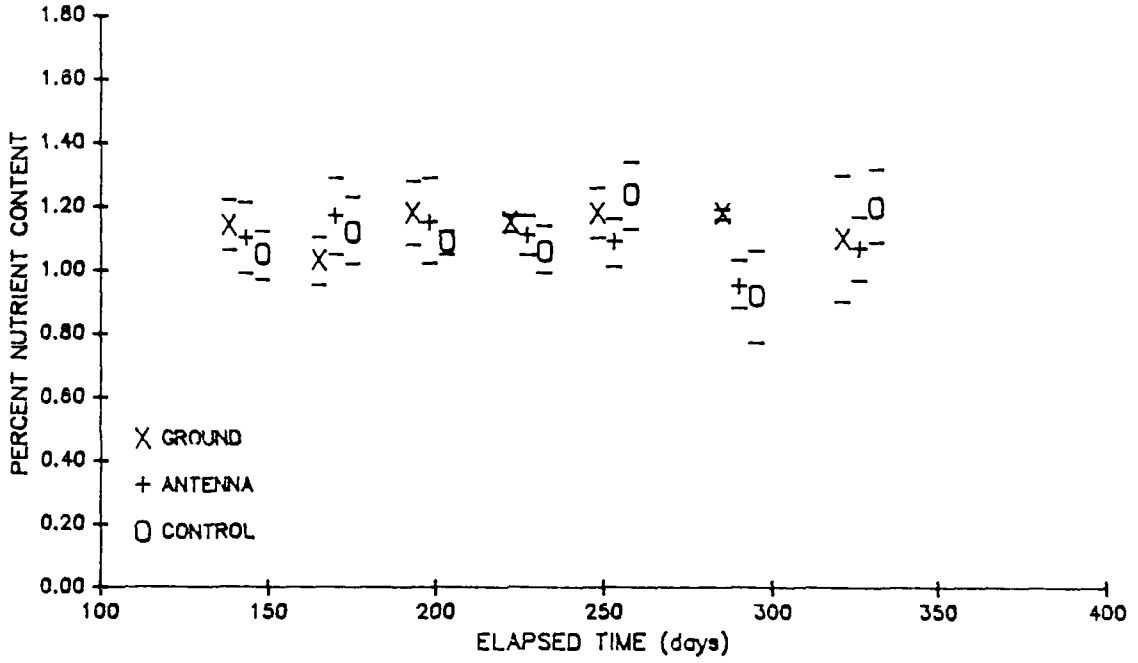

FIGURE 104. Percent calcium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

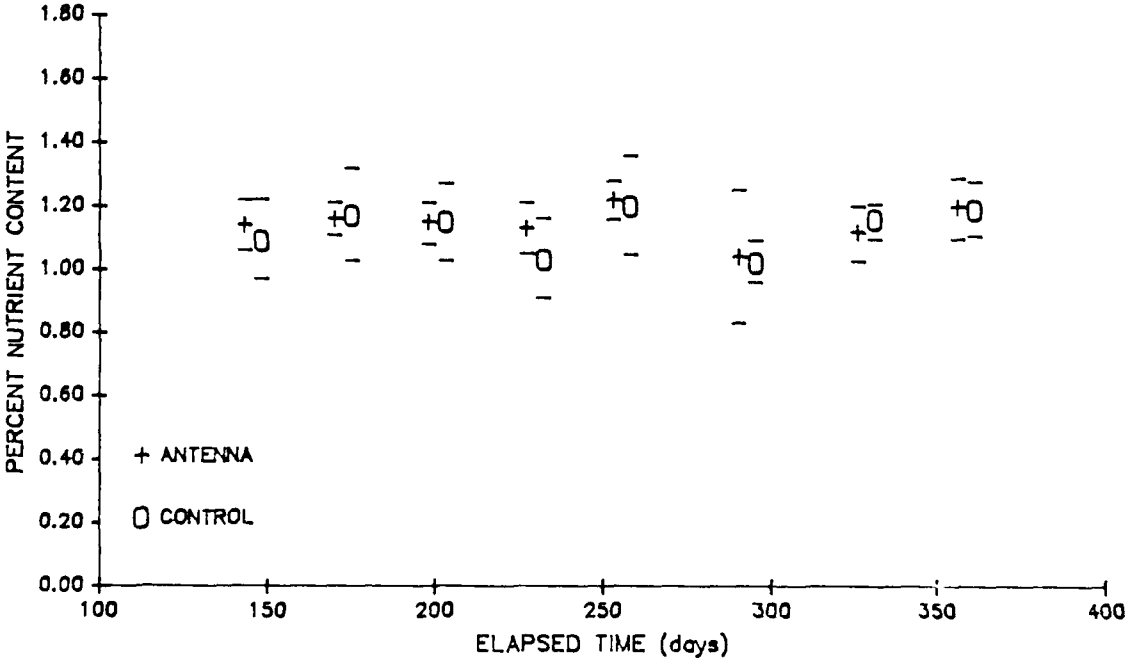

FIGURE 105. Percent calcium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

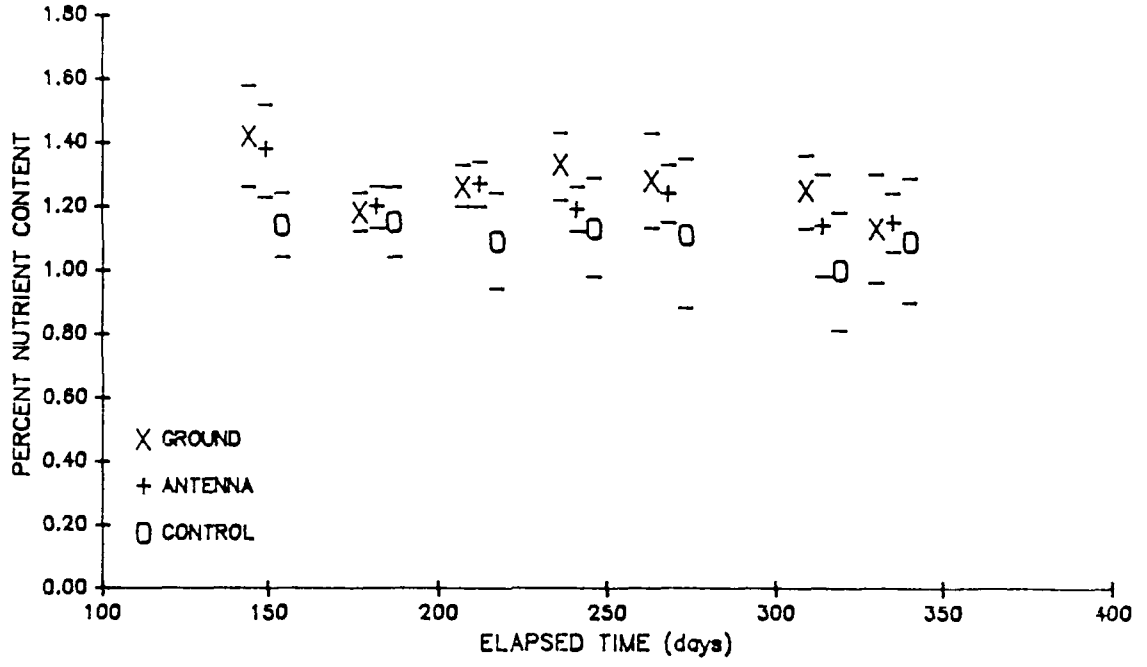

FIGURE 106. Percent calcium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

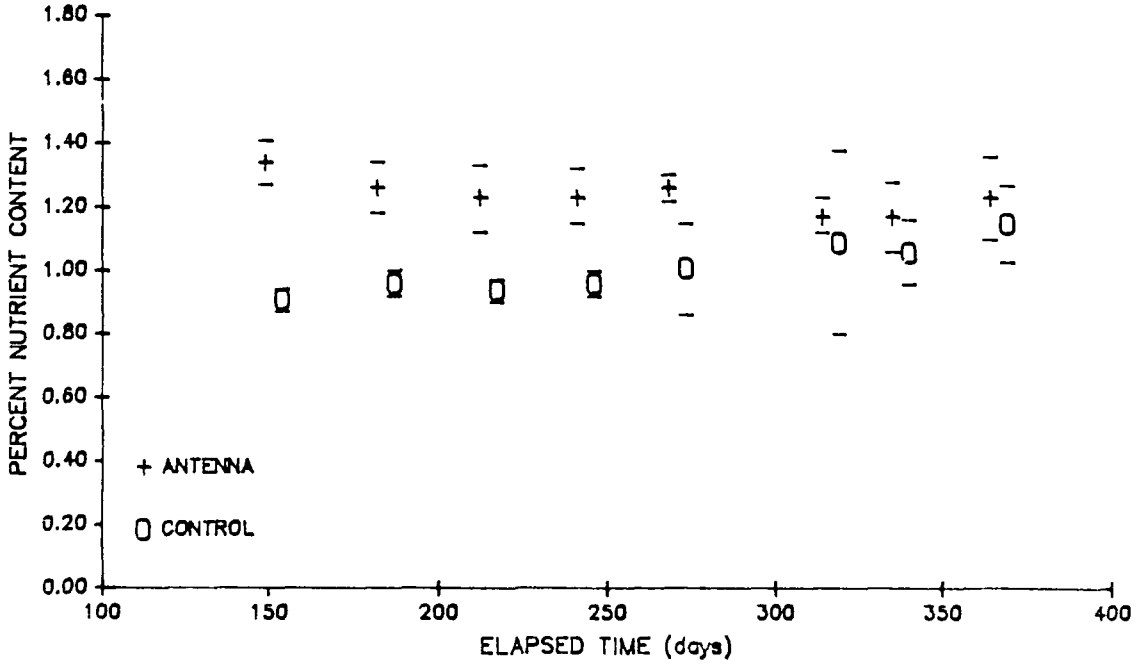

FIGURE 107. Percent calcium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

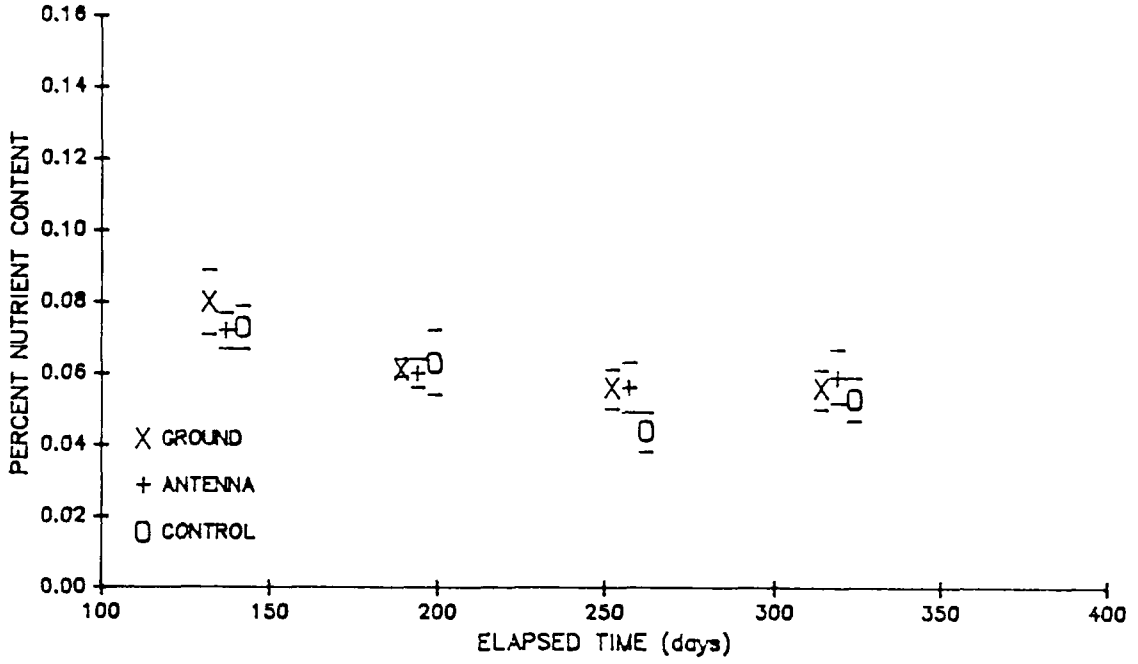

FIGURE 108. Percent magnesium content of bulk pine needle samples retrieved from the three plantation subunits during the 1986–1987 experiment.

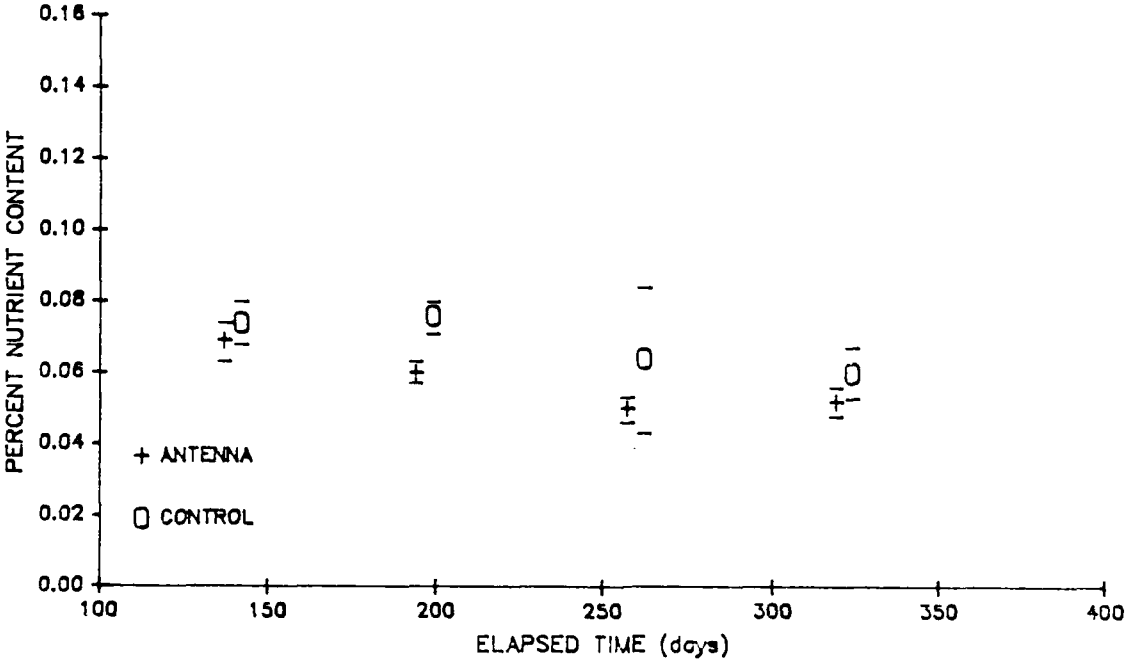

FIGURE 109. Percent magnesium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

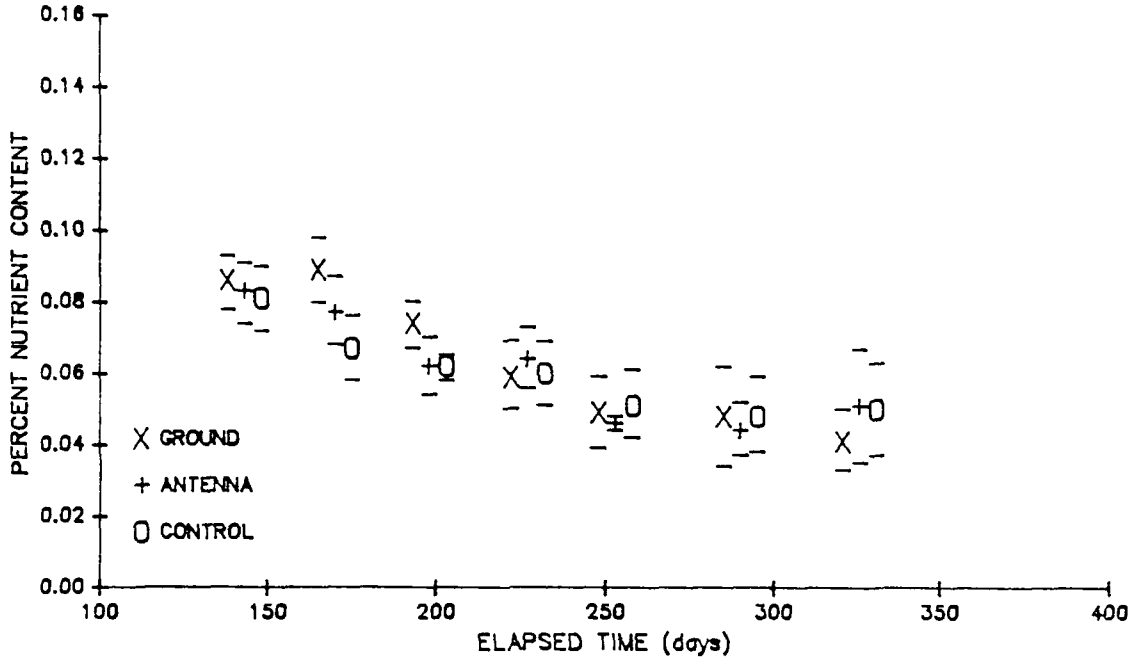

FIGURE 110. Percent magnesium content of bulk pine needle samples retrieved from the three plantation subunits during the 1985–1986 experiment.

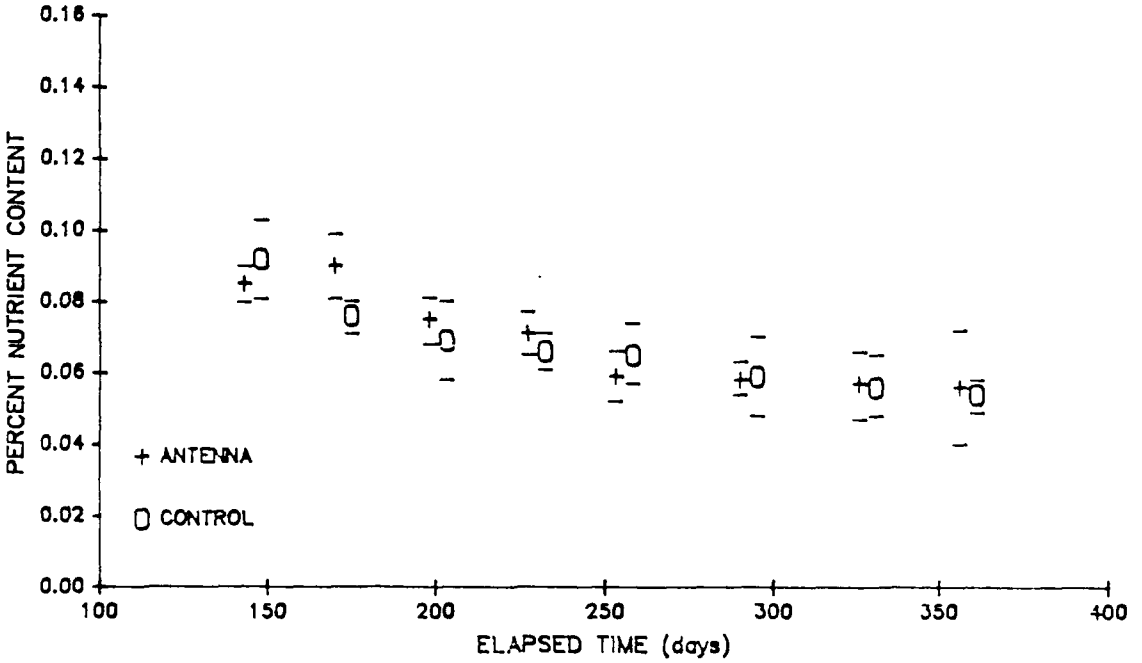

FIGURE 111. Percent magnesium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

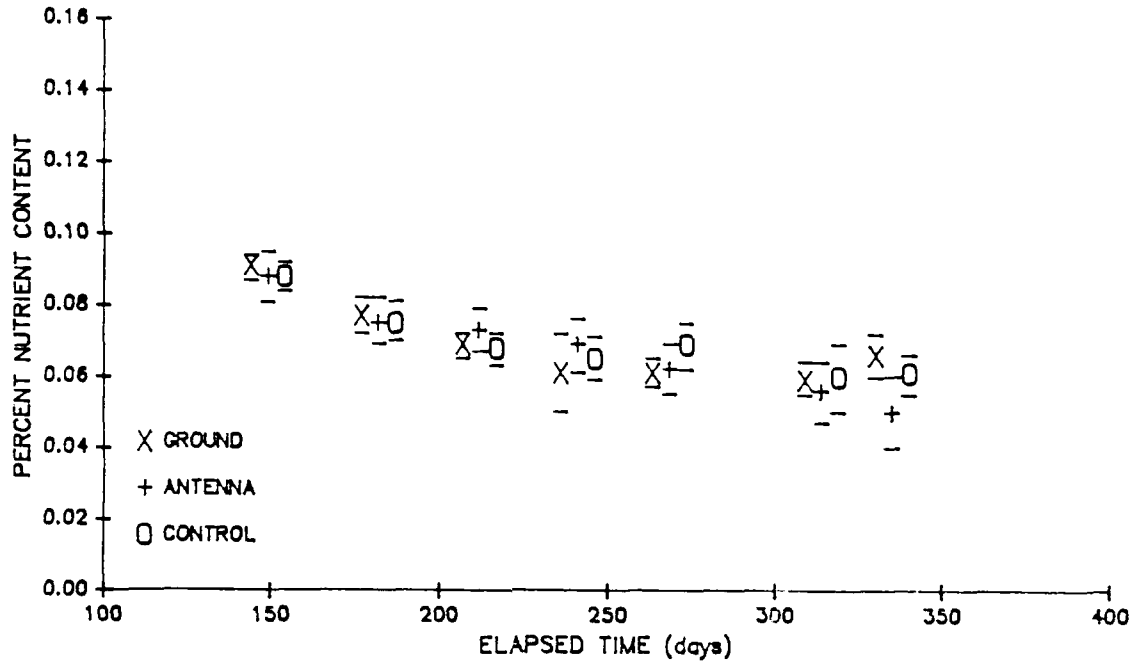

FIGURE 112. Percent magnesium content of bulk pine needle samples retrieved from the three plantation subunits during the 1984–1985 experiment.

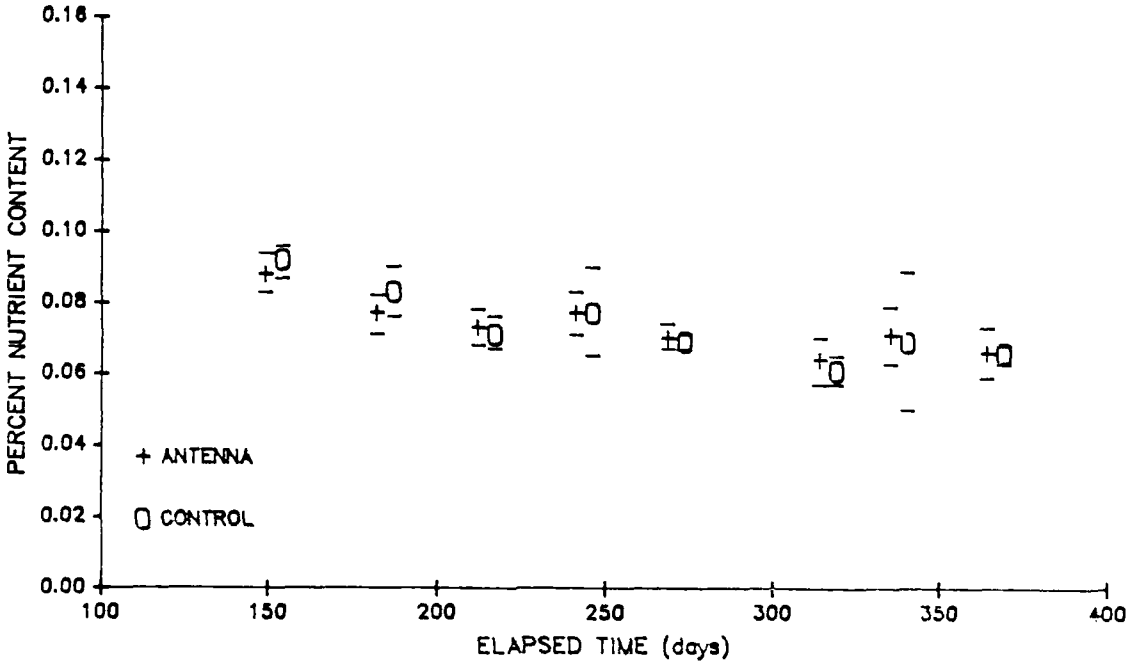

FIGURE 113. Percent magnesium content of bulk pine needle samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

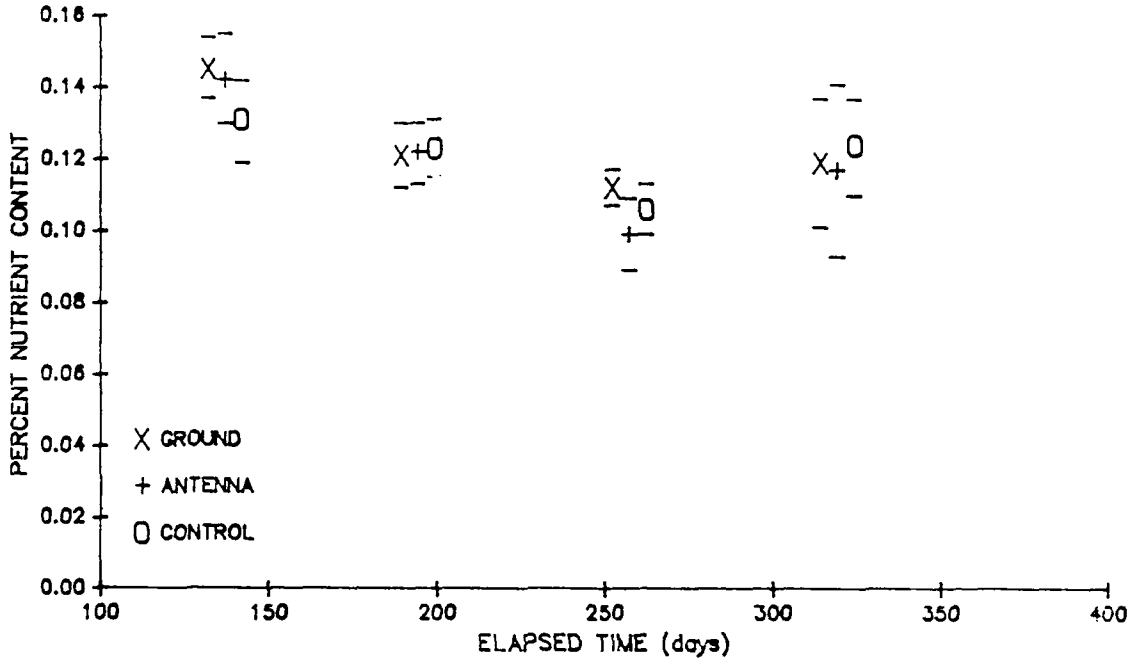

FIGURE 114. Percent magnesium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

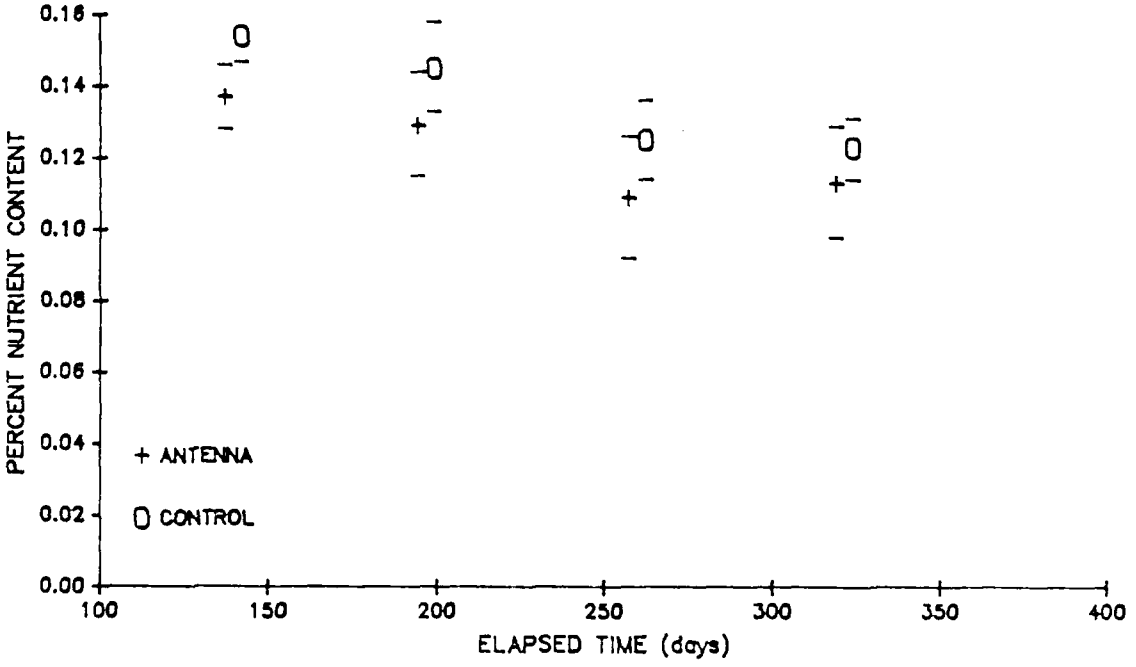

FIGURE 115. Percent magnesium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

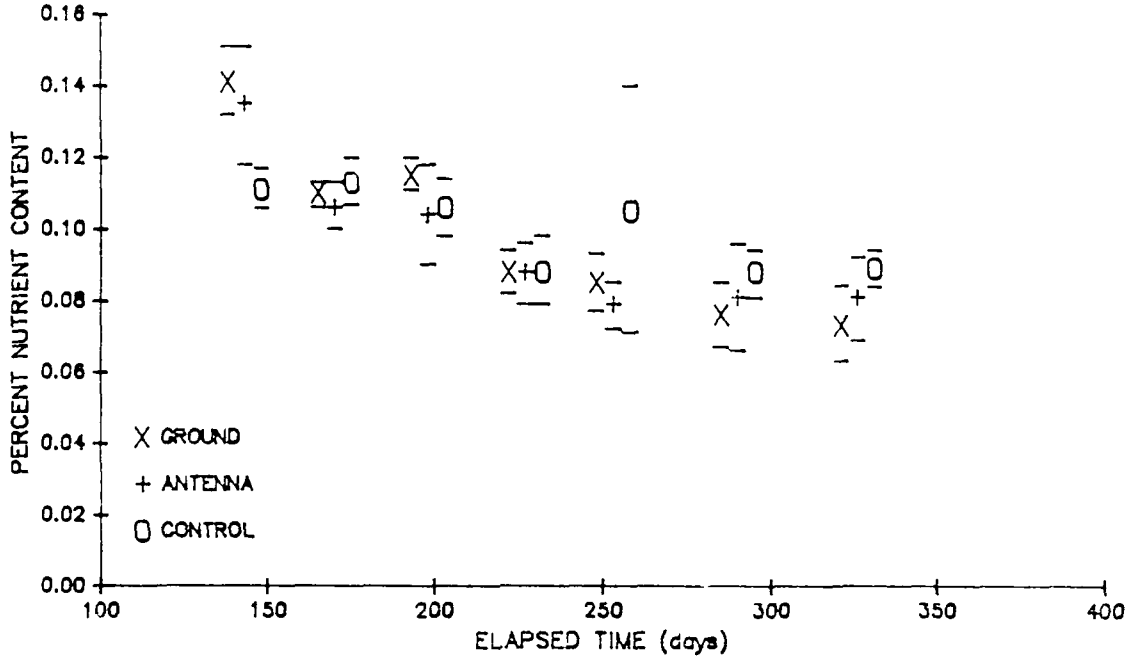

FIGURE 116. Percent magnesium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

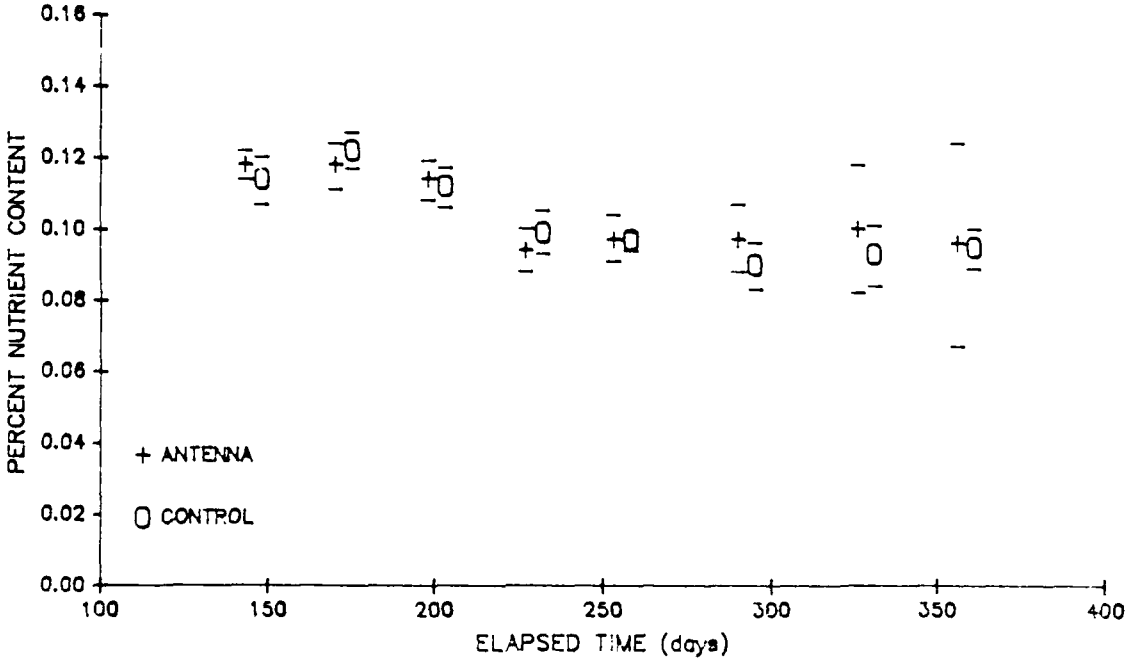

FIGURE 117. Percent magnesium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

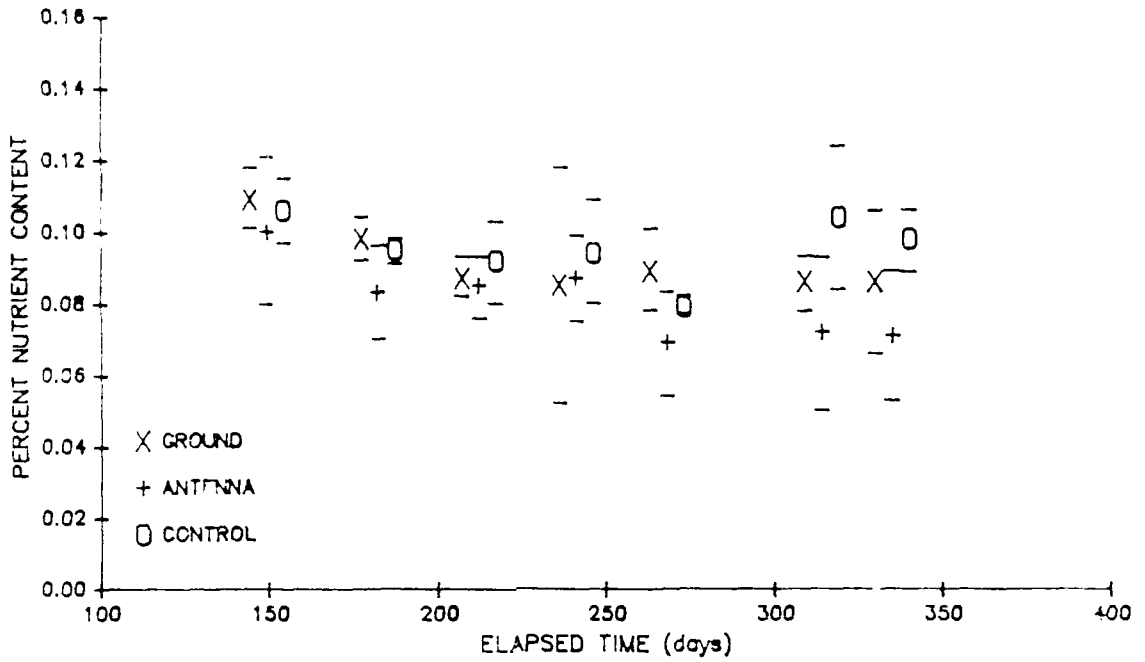

FIGURE 118. Percent magnesium content of bulk oak leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

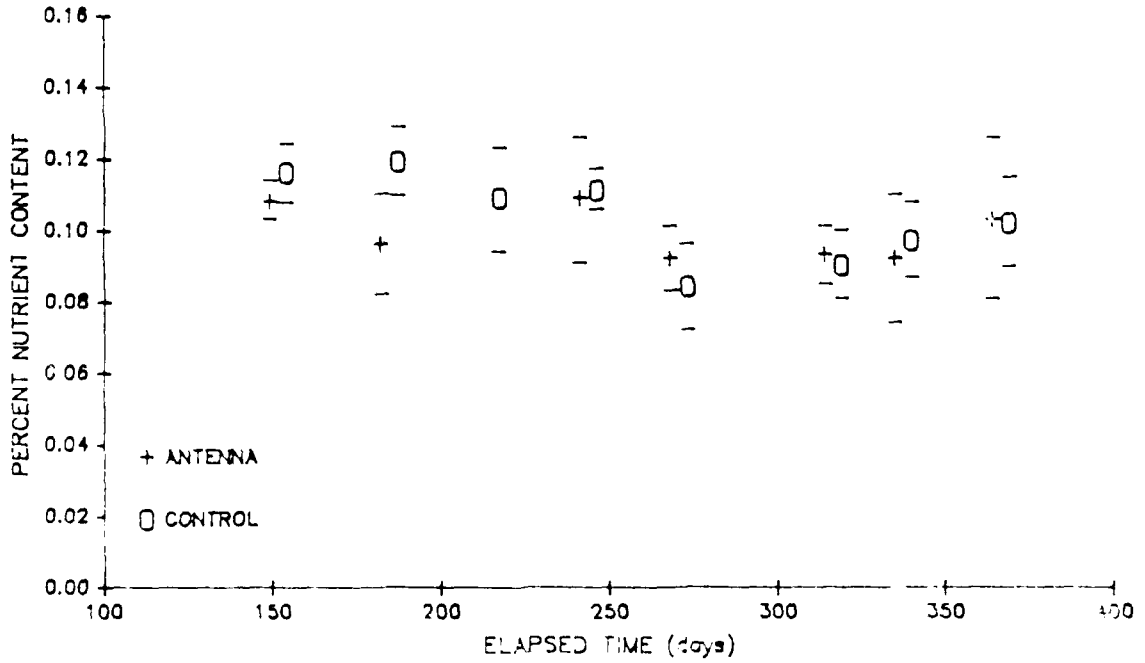

FIGURE 119. Percent magnesium content of bulk oak leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

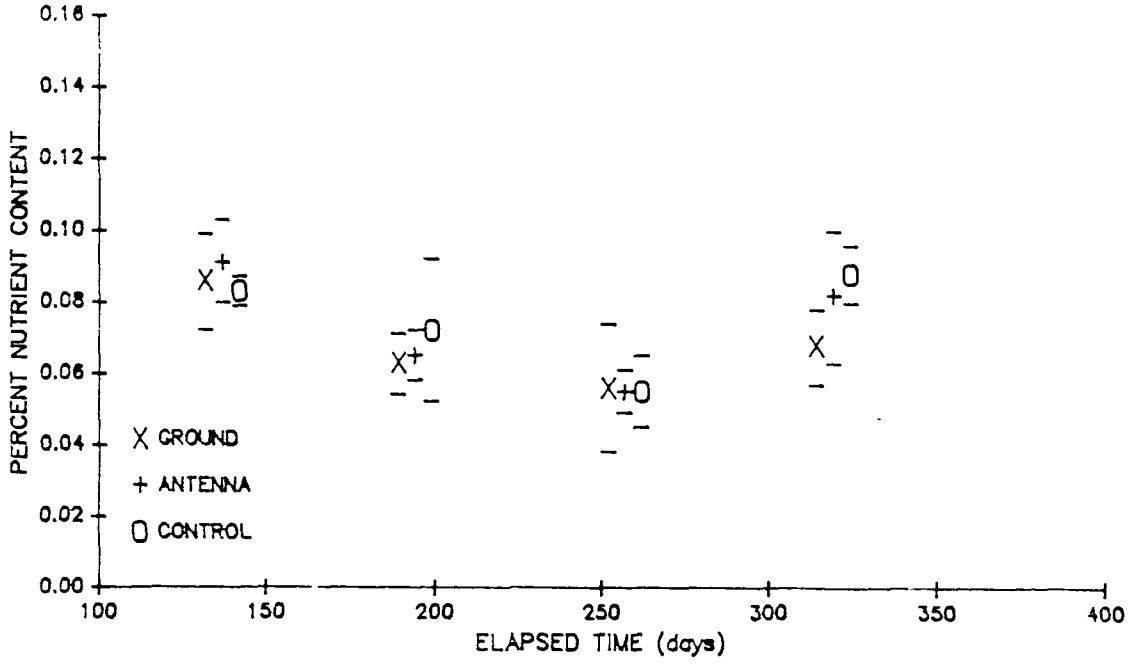

FIGURE 120. Percent magnesium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1986–1987 experiment.

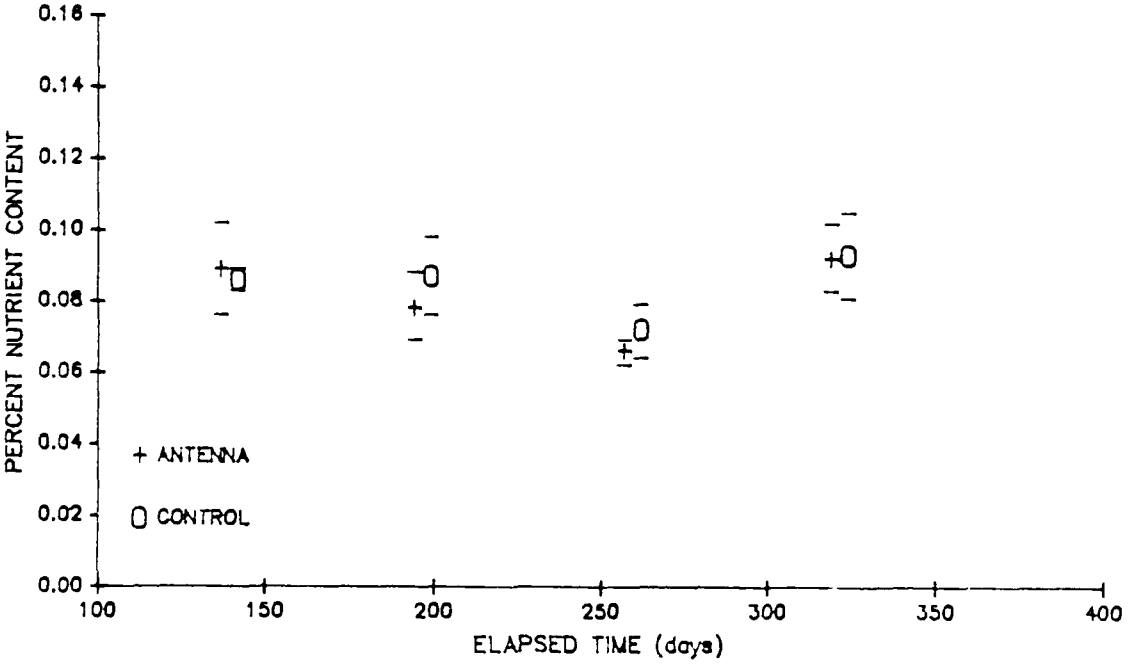

FIGURE 121. Percent magnesium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1986–1987 experiment.

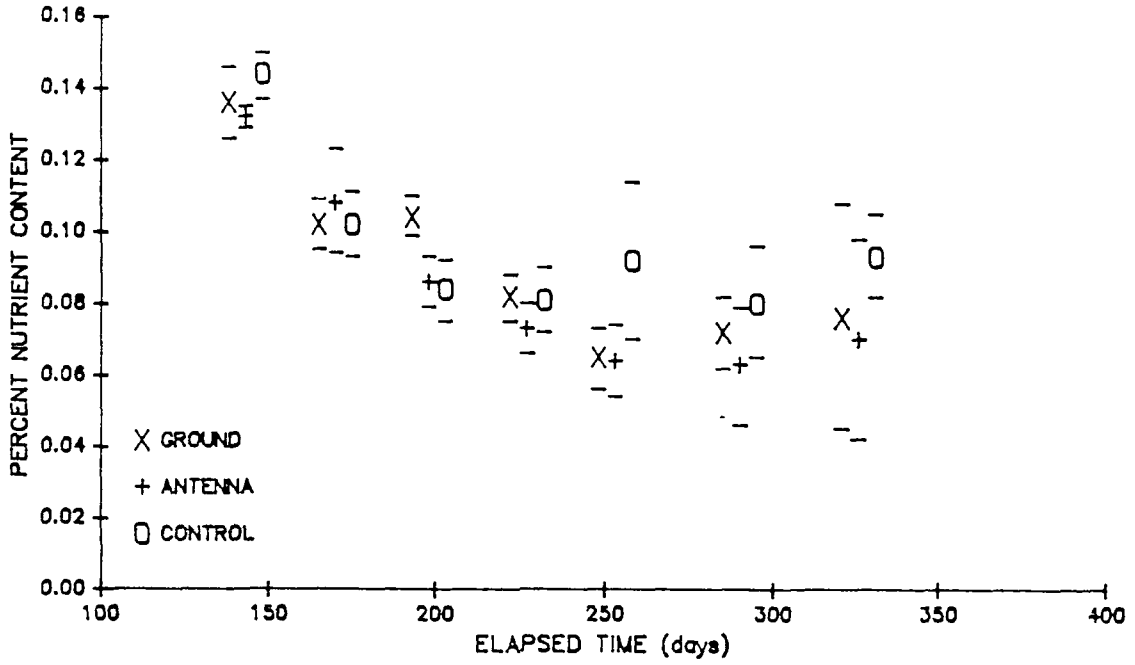

FIGURE 122. Percent magnesium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1985–1986 experiment.

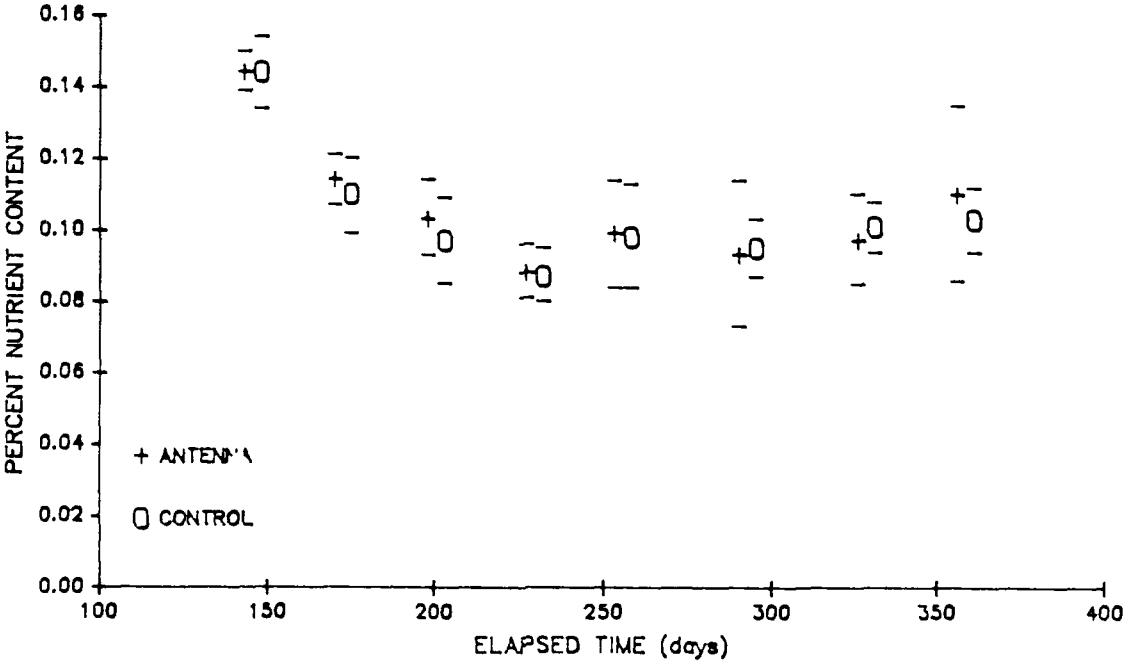

FIGURE 123. Percent magnesium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1985–1986 experiment.

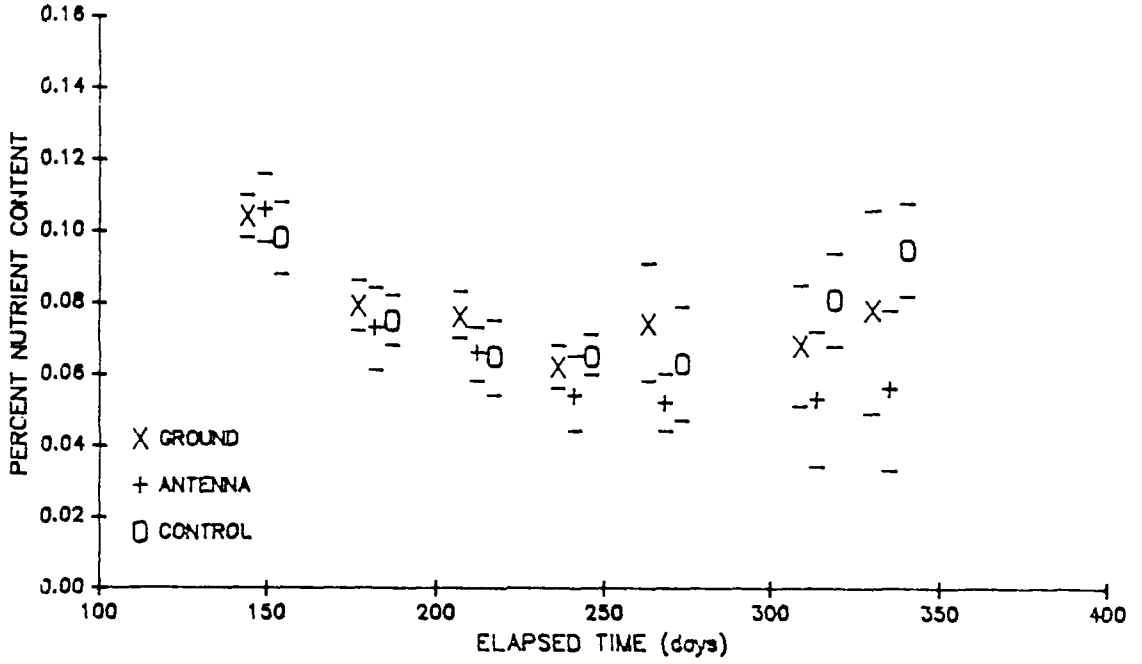

FIGURE 124. Percent magnesium content of bulk maple leaf samples retrieved from the three plantation subunits during the 1984–1985 experiment.

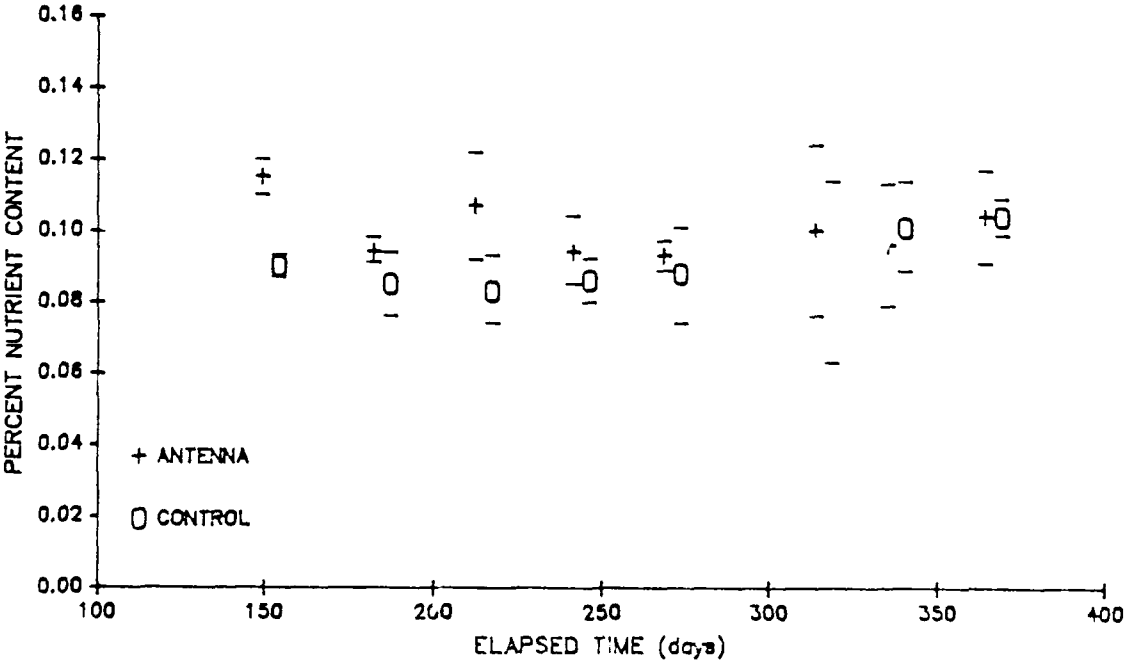

FIGURE 125. Percent magnesium content of bulk maple leaf samples retrieved from the two hardwood stand subunits during the 1984–1985 experiment.

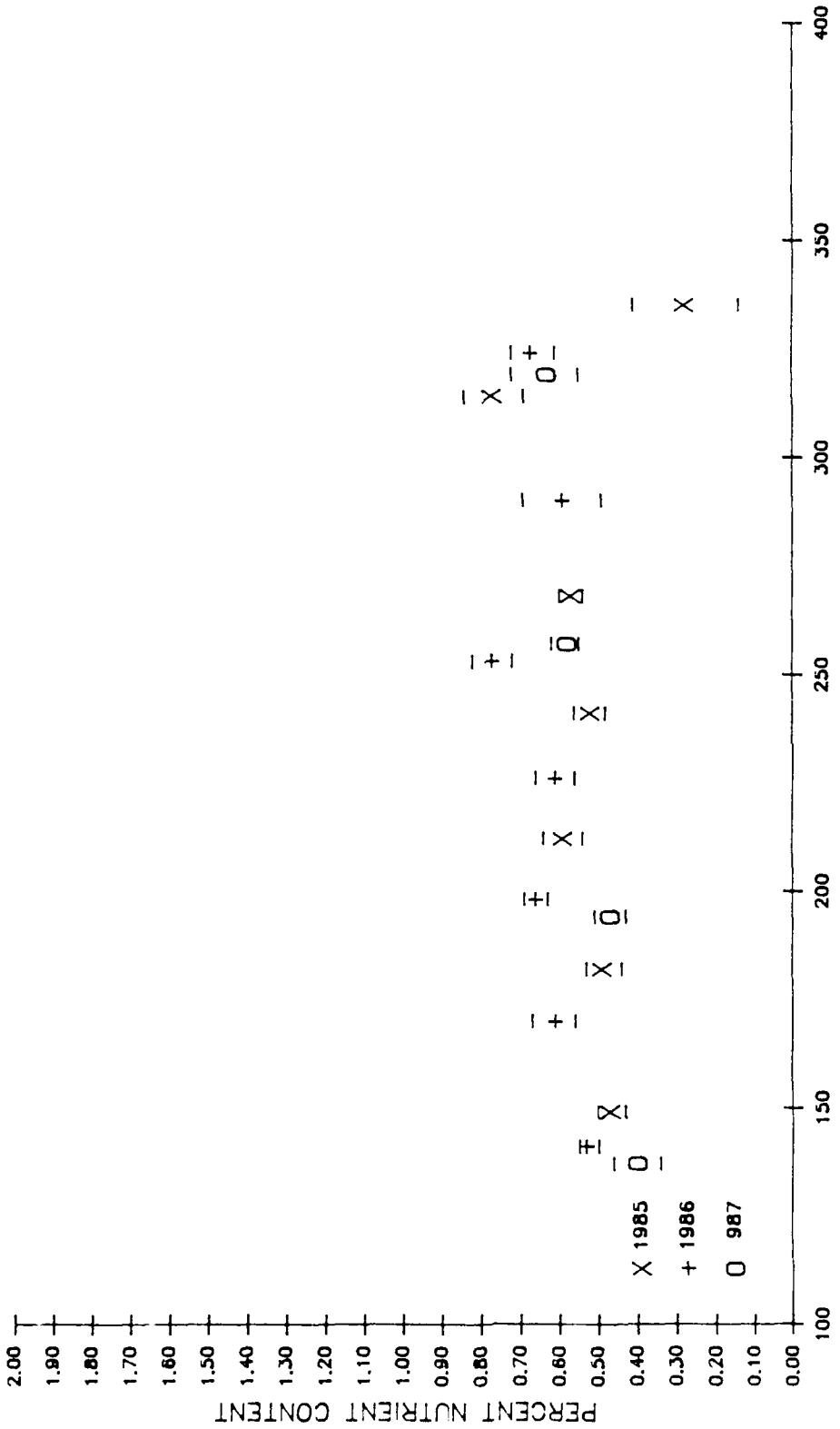

FIGURE 126. Percent nitrogen content of bulk pine needle samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

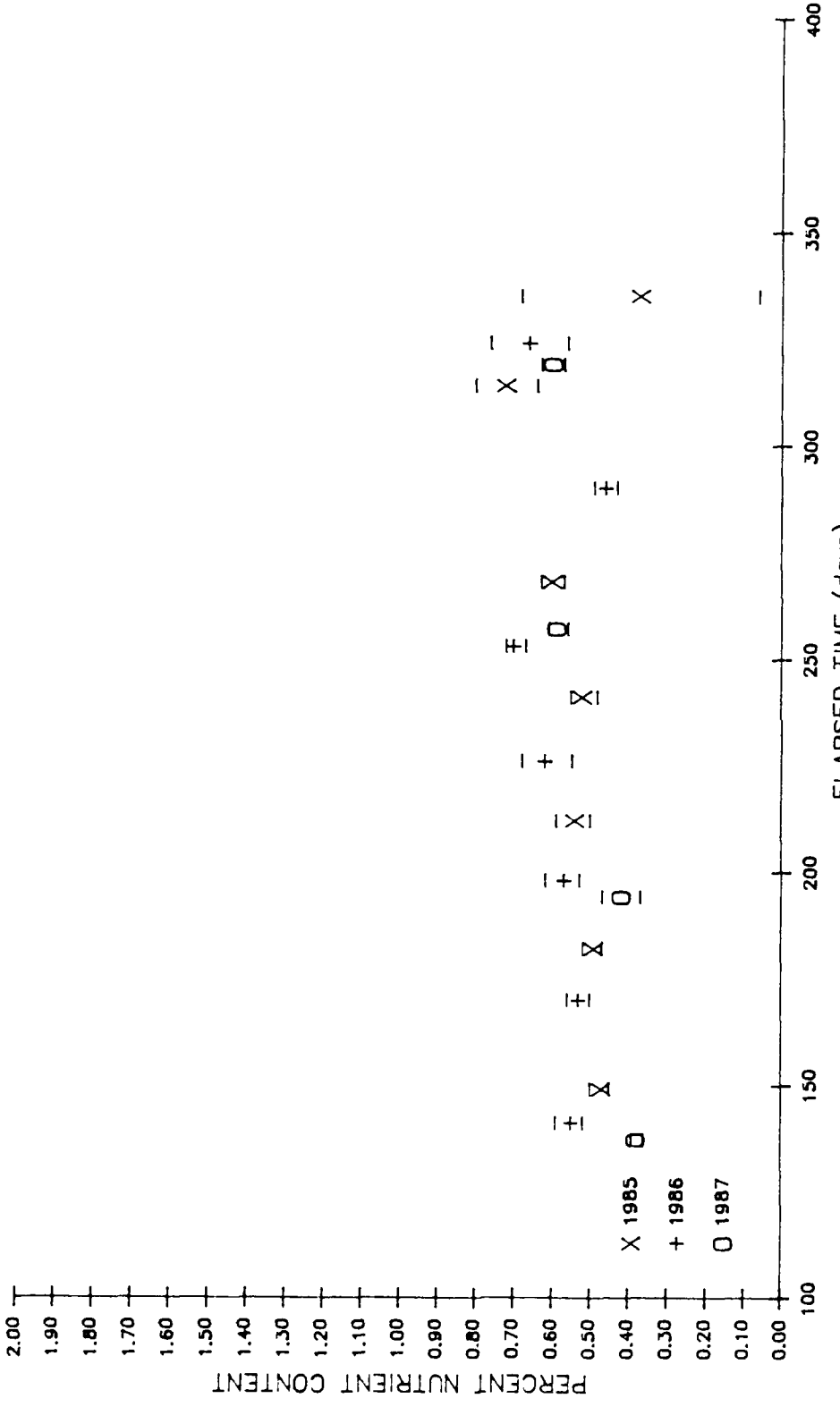

FIGURE 127. Percent nitrogen content of bulk pine needle samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

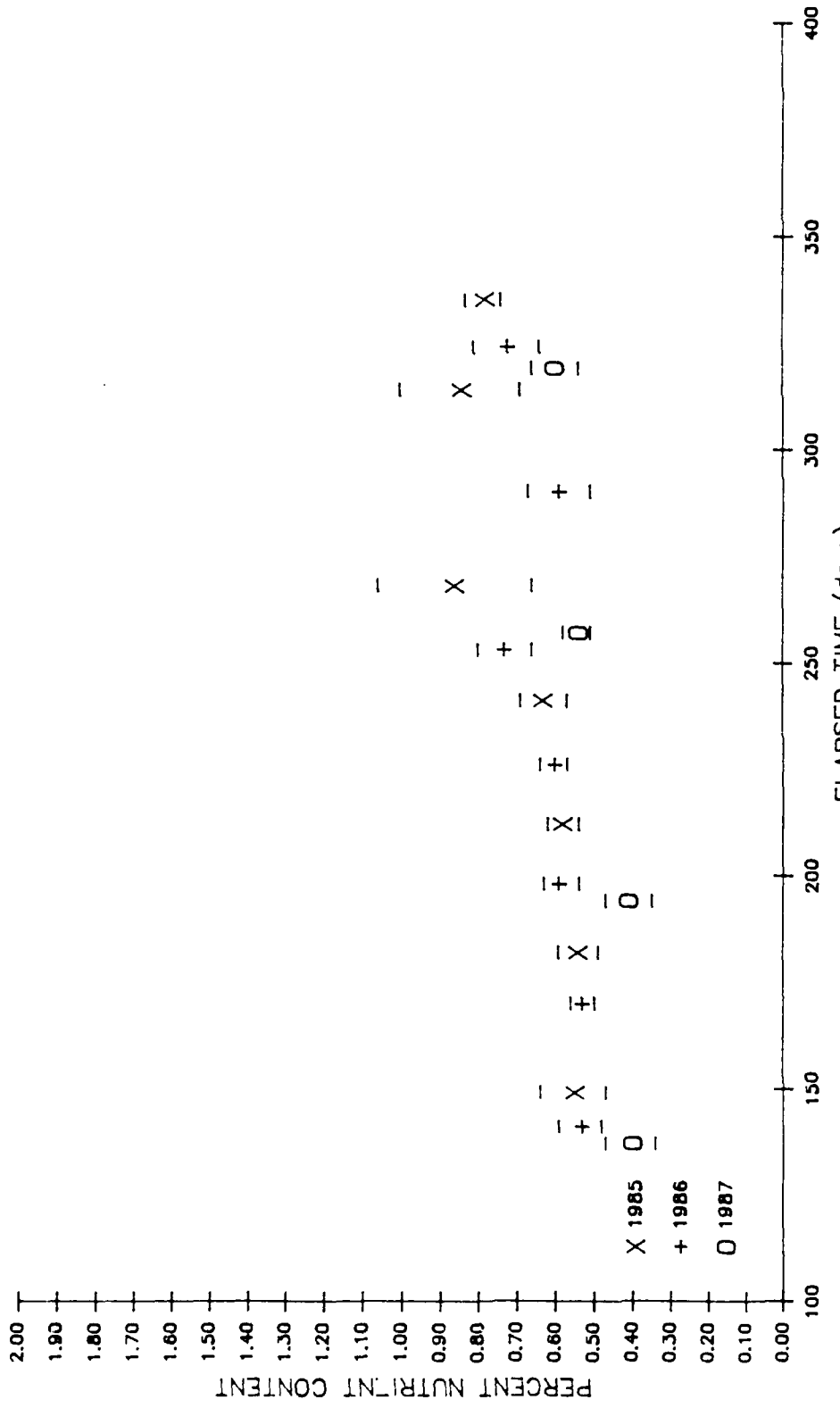

FIGURE 128. Percent nitrogen content of bulk pine needle samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

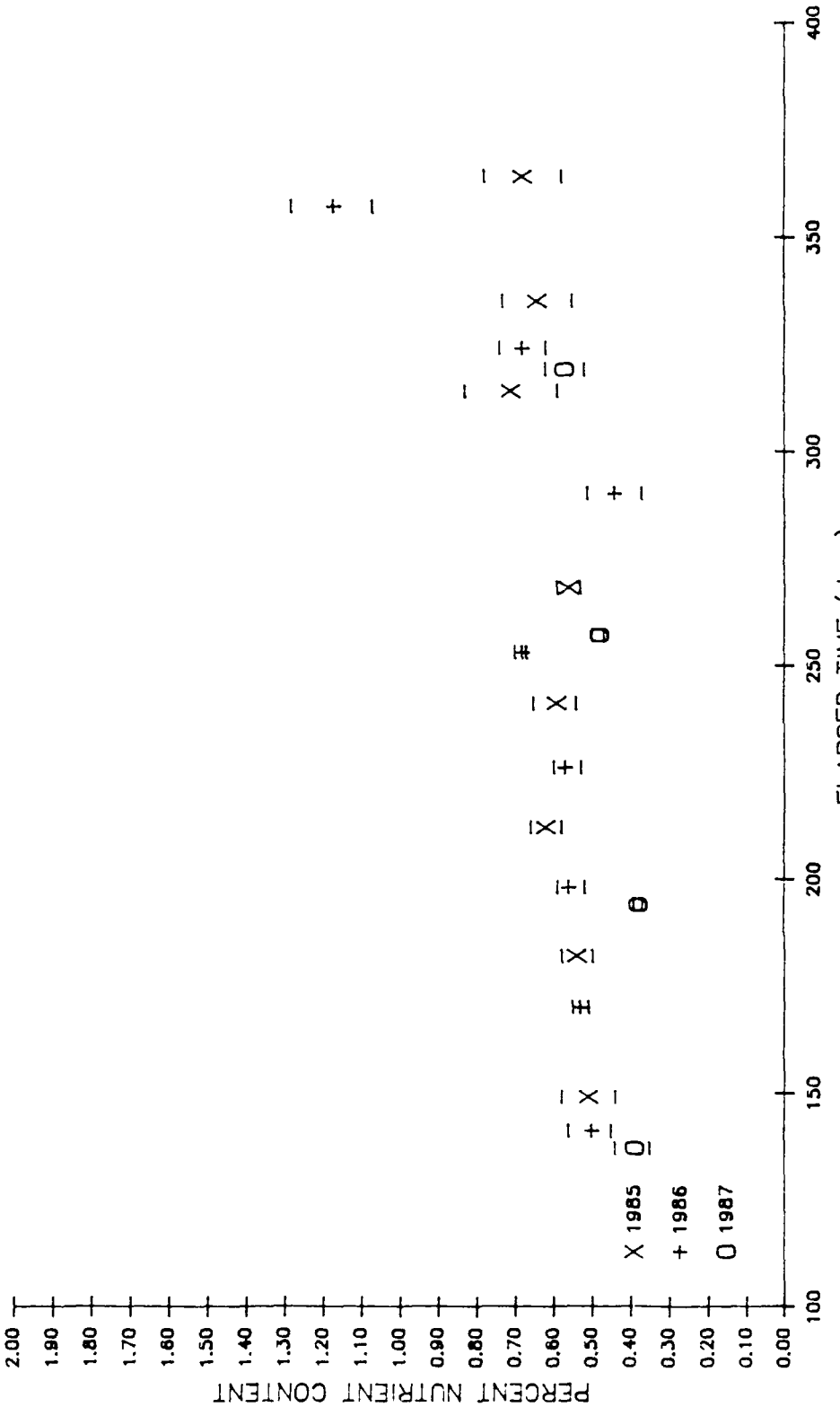

FIGURE 129. Percent nitrogen content of bulk pine needle samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

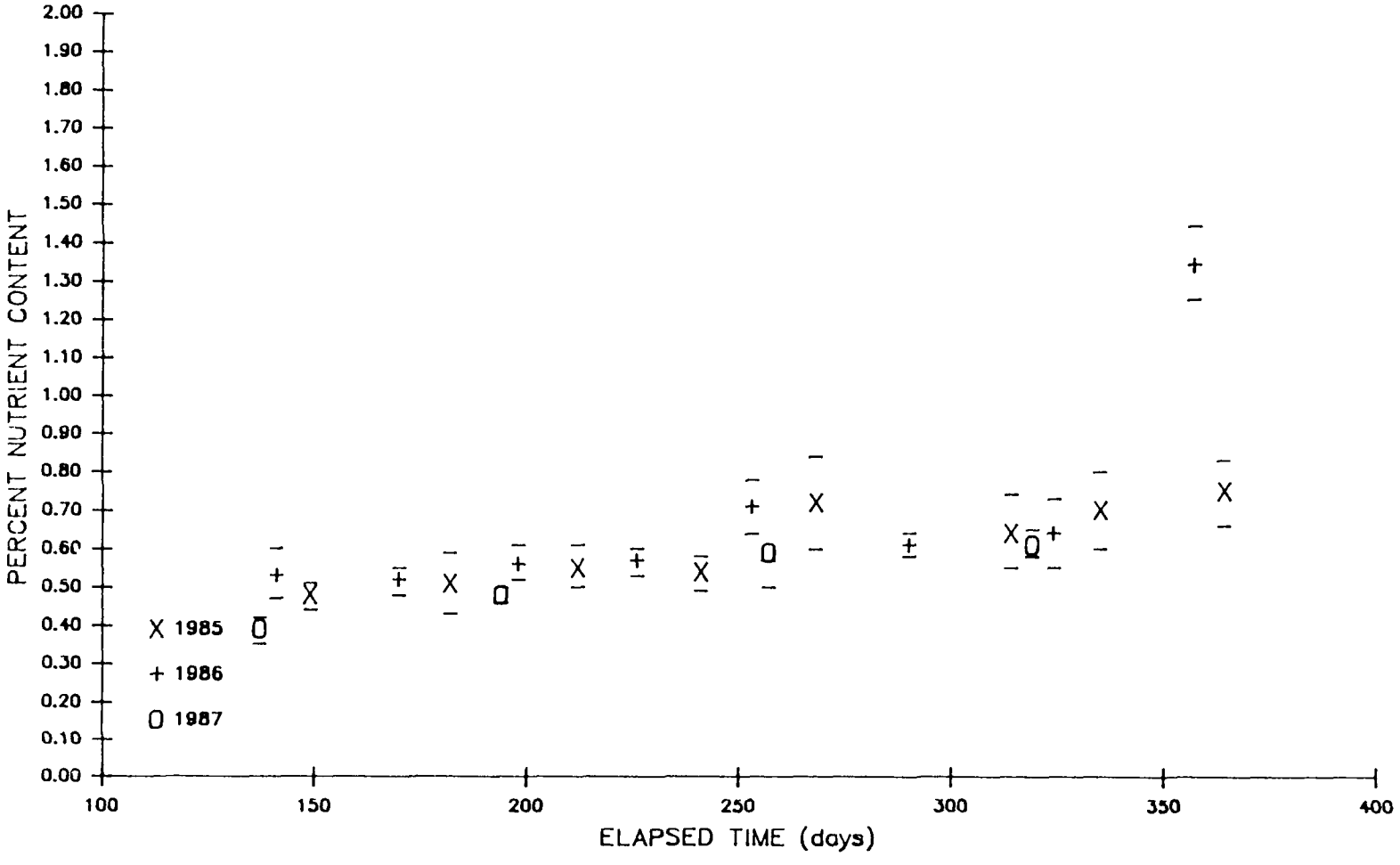

FIGURE 130. Percent nitrogen content of bulk pine needle samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

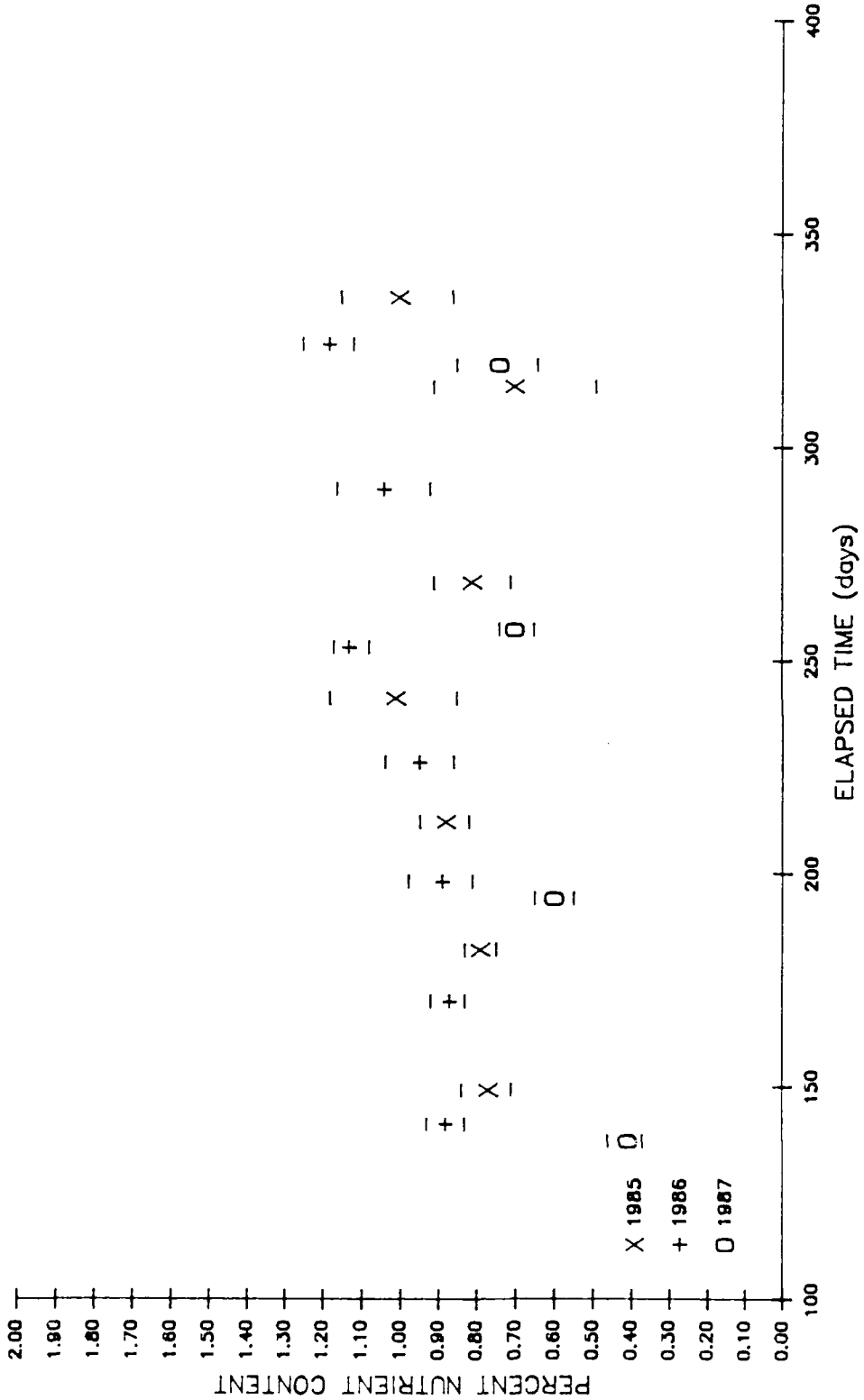

FIGURE 131. Percent nitrogen content of bulk oak leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

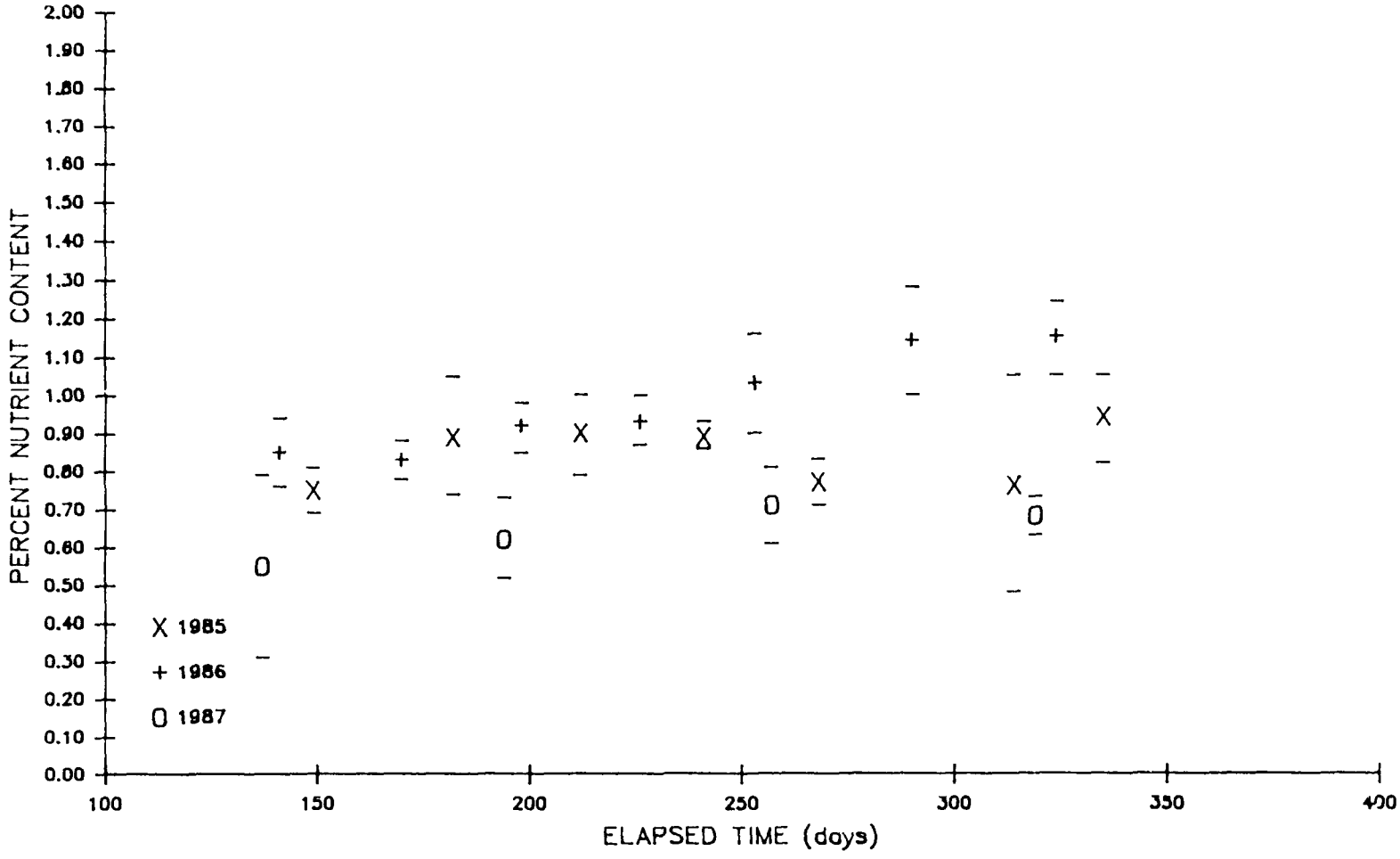

FIGURE 132. Percent nitrogen content of bulk oak leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

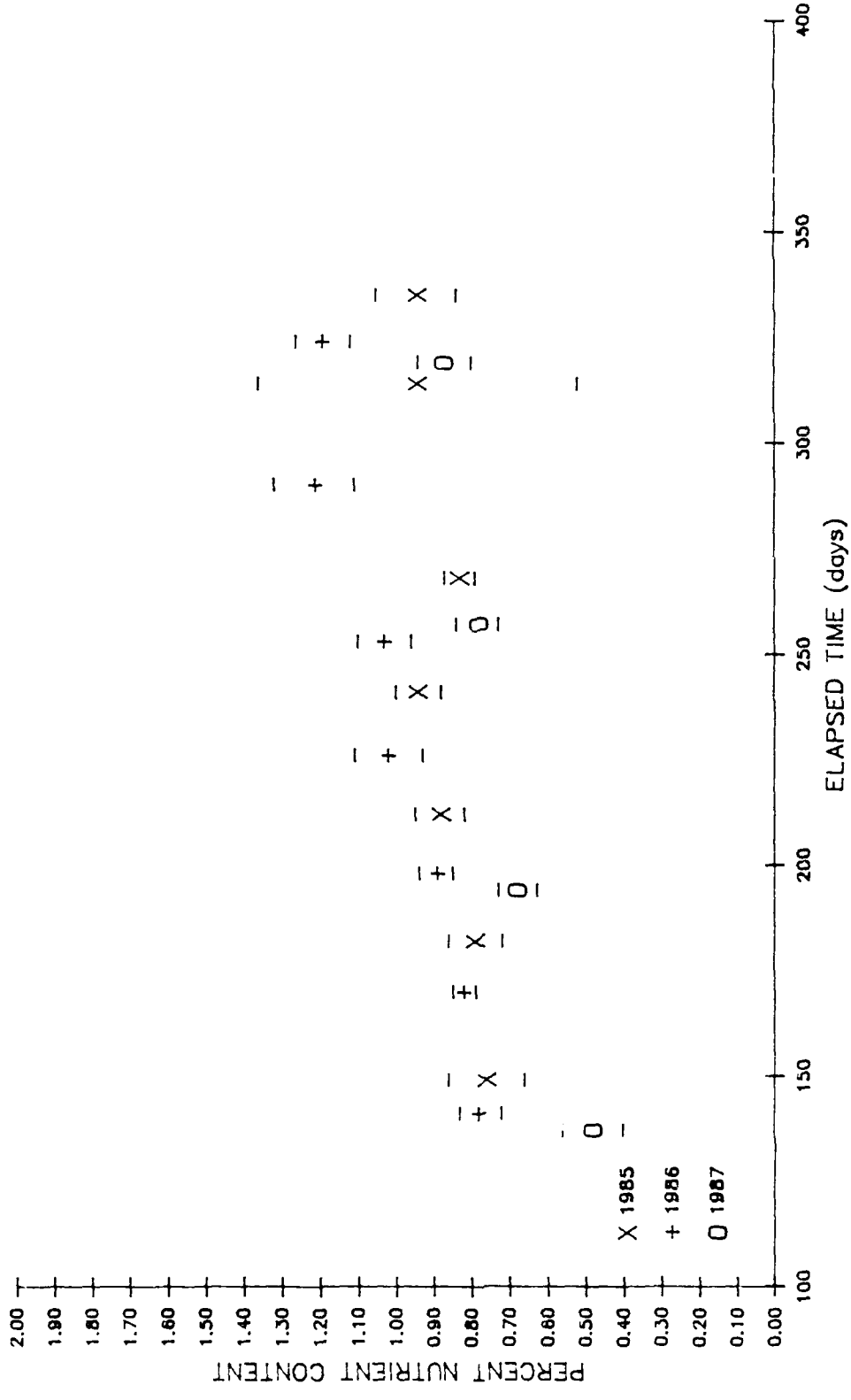

FIGURE 133. Percent nitrogen content of bulk oak leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

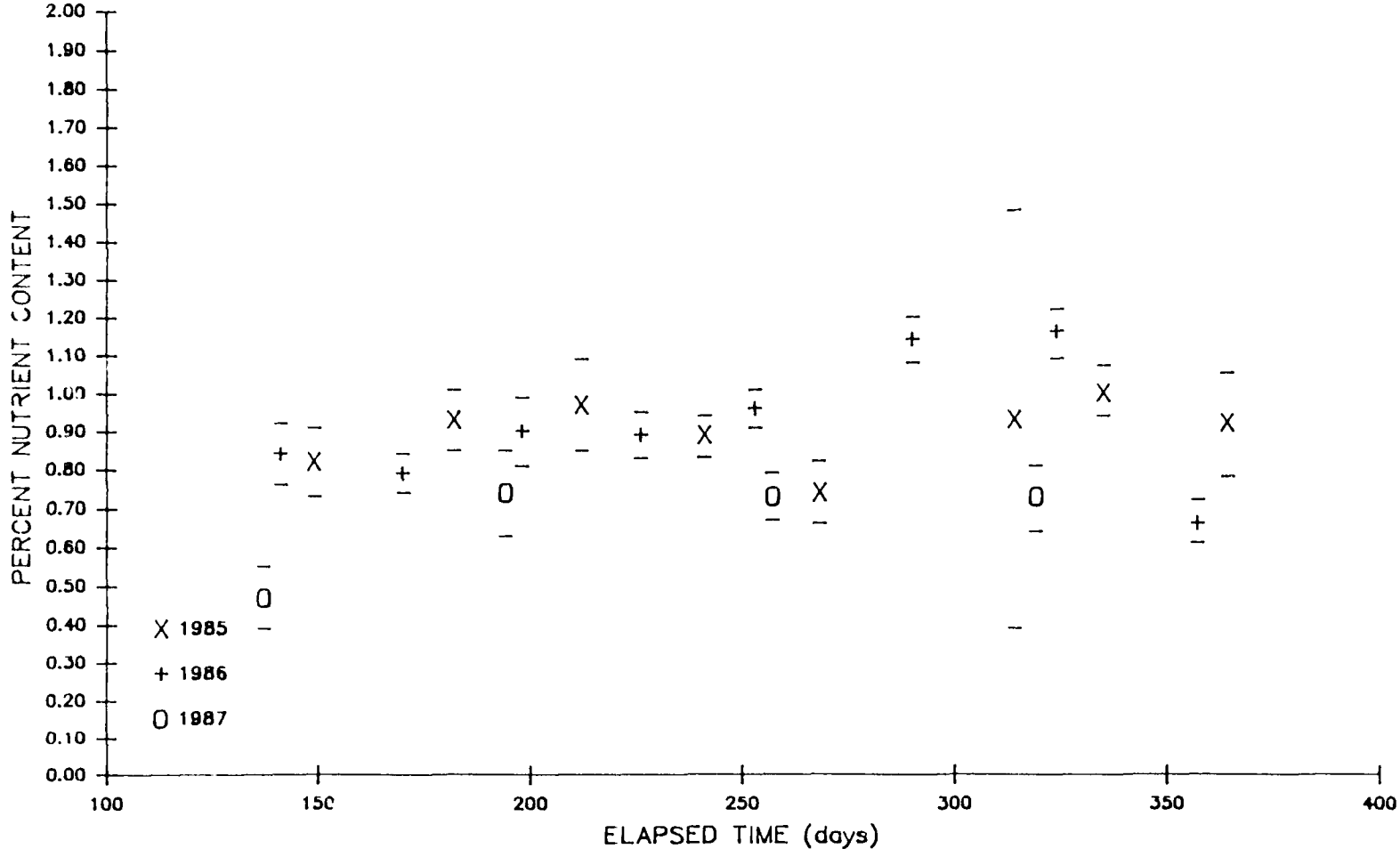

FIGURE 134. Percent nitrogen content of bulk oak leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

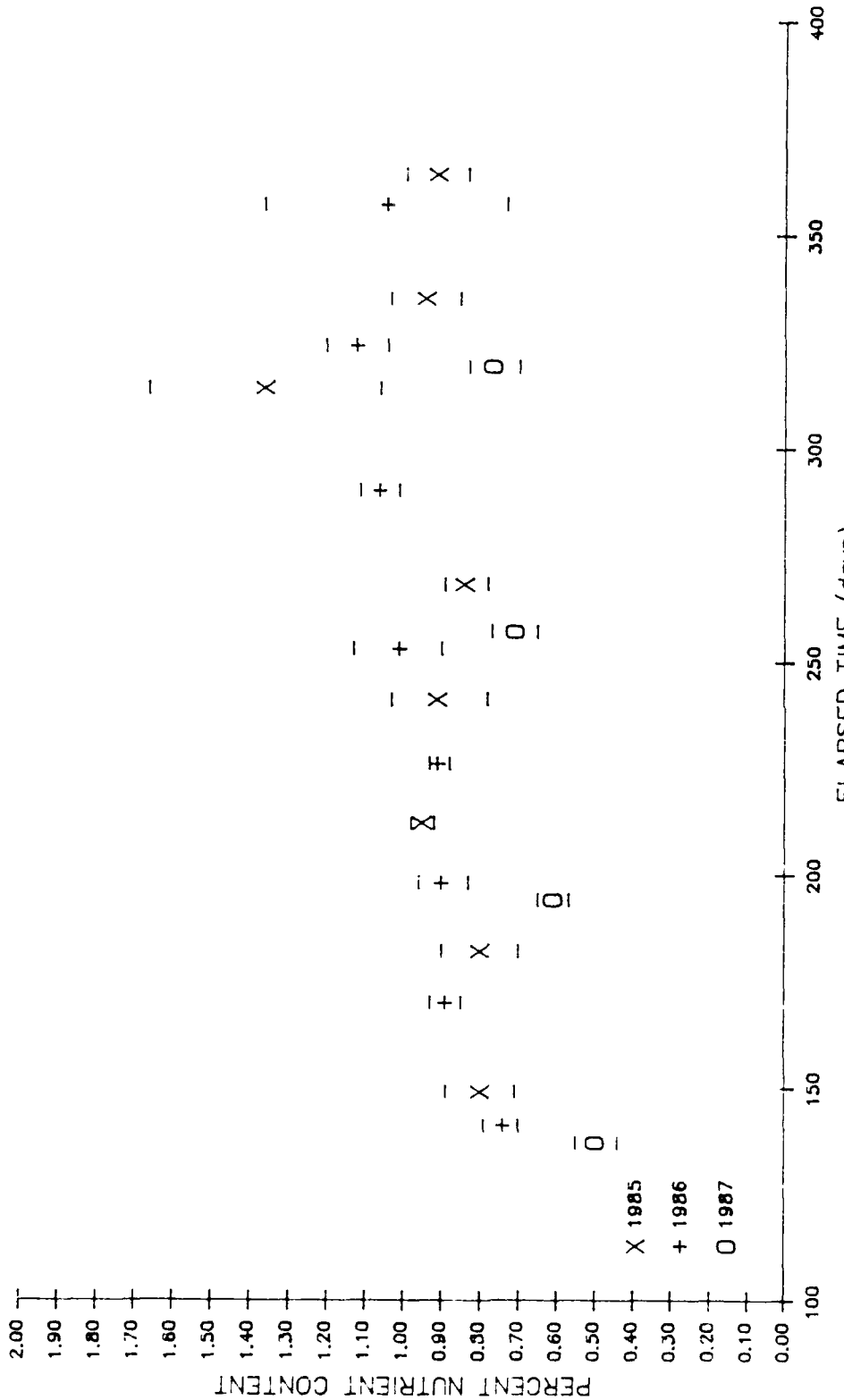

FIGURE 135. Percent nitrogen content of bulk oak leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

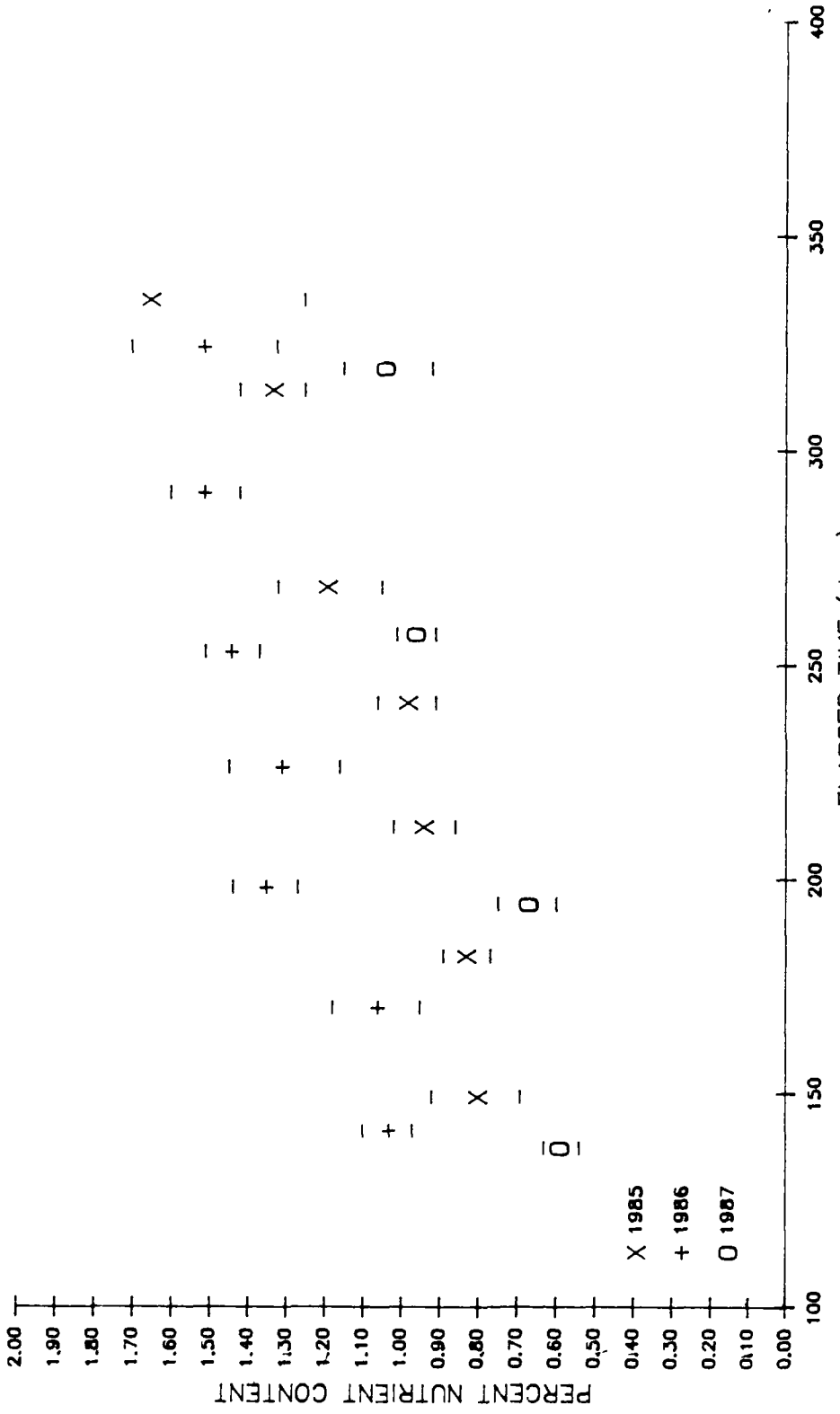

FIGURE 136. Percent nitrogen content of bulk maple leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

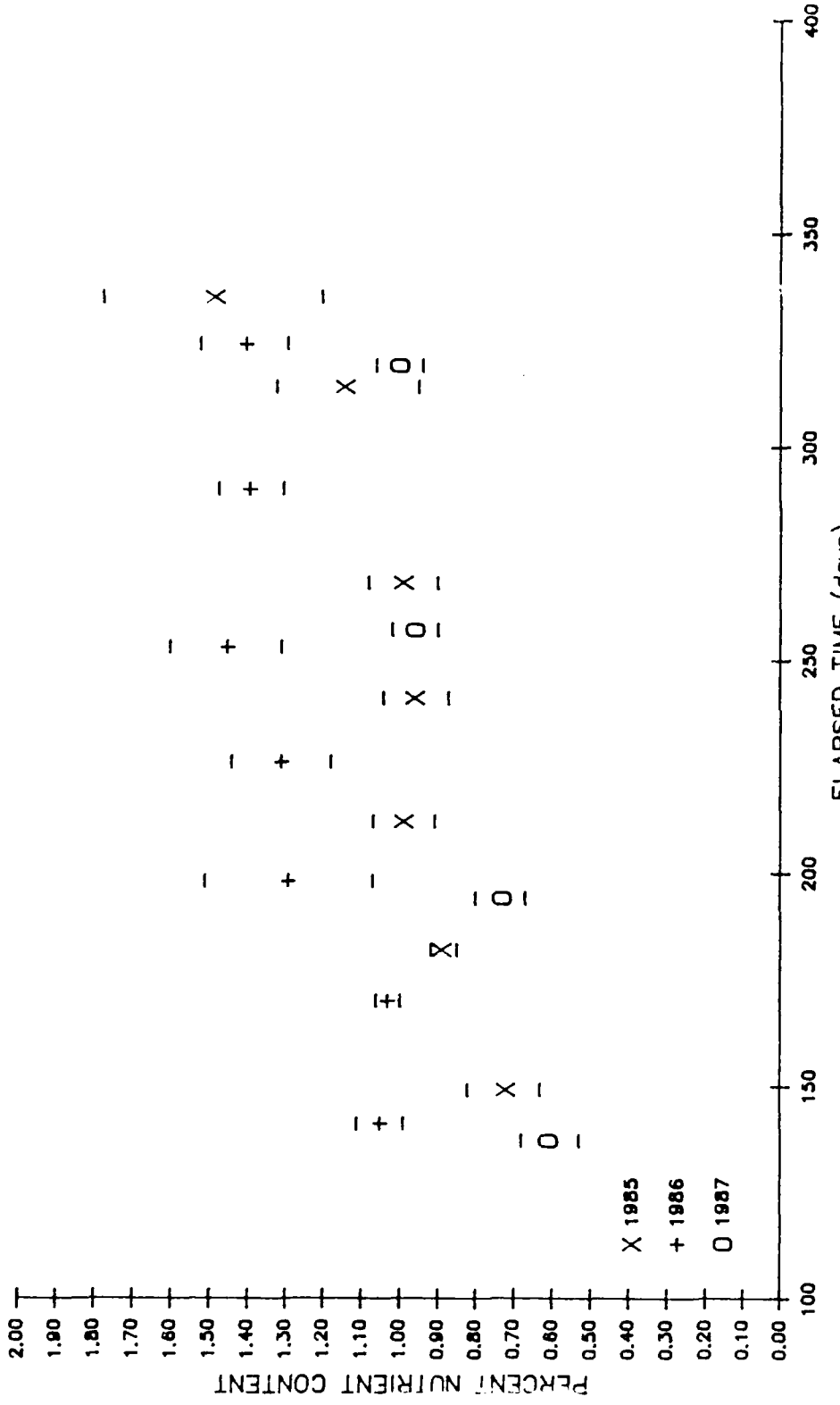

FIGURE 137. Percent nitrogen content of bulk maple leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

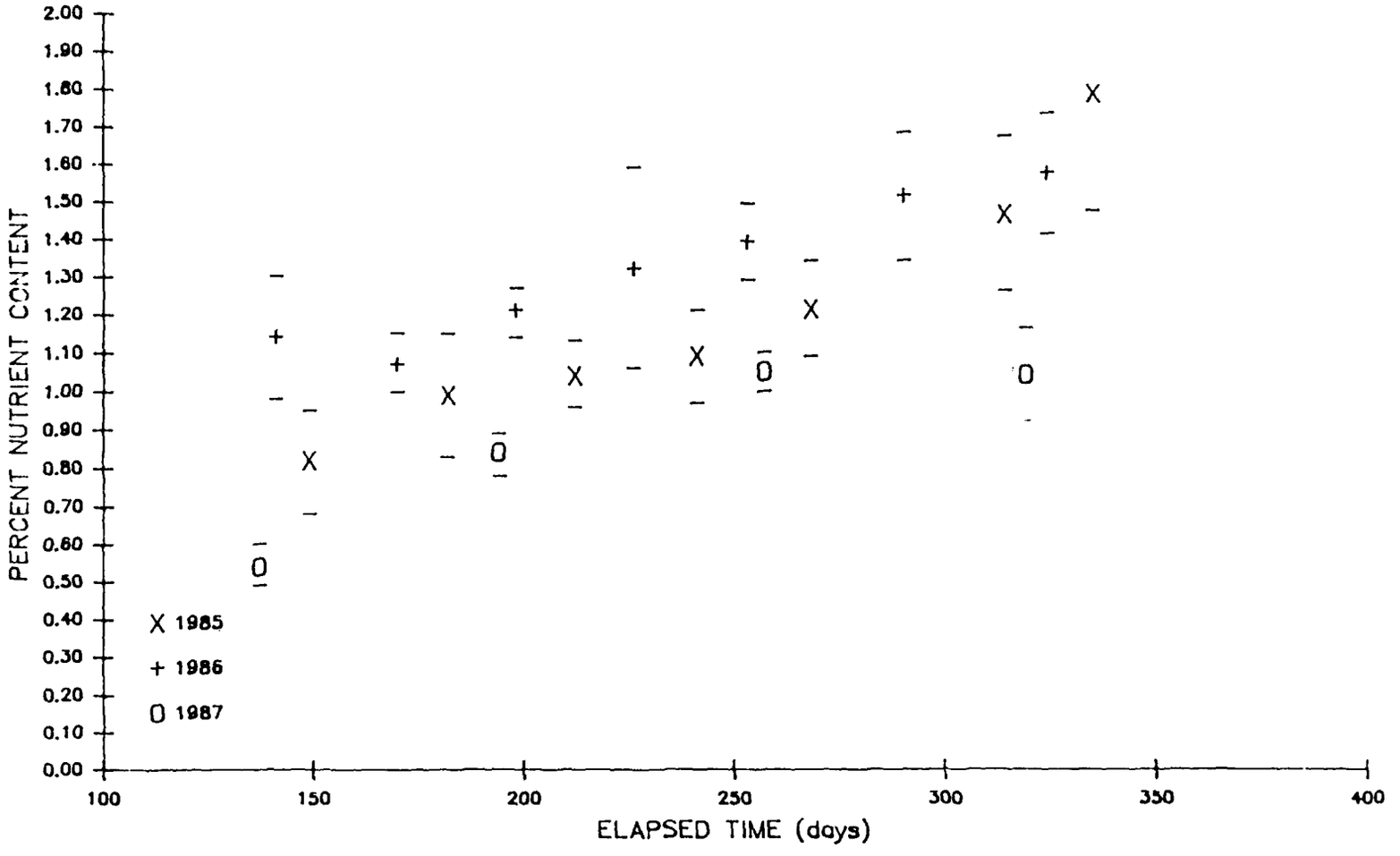

FIGURE 138. *Percent nitrogen content of bulk maple leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.*

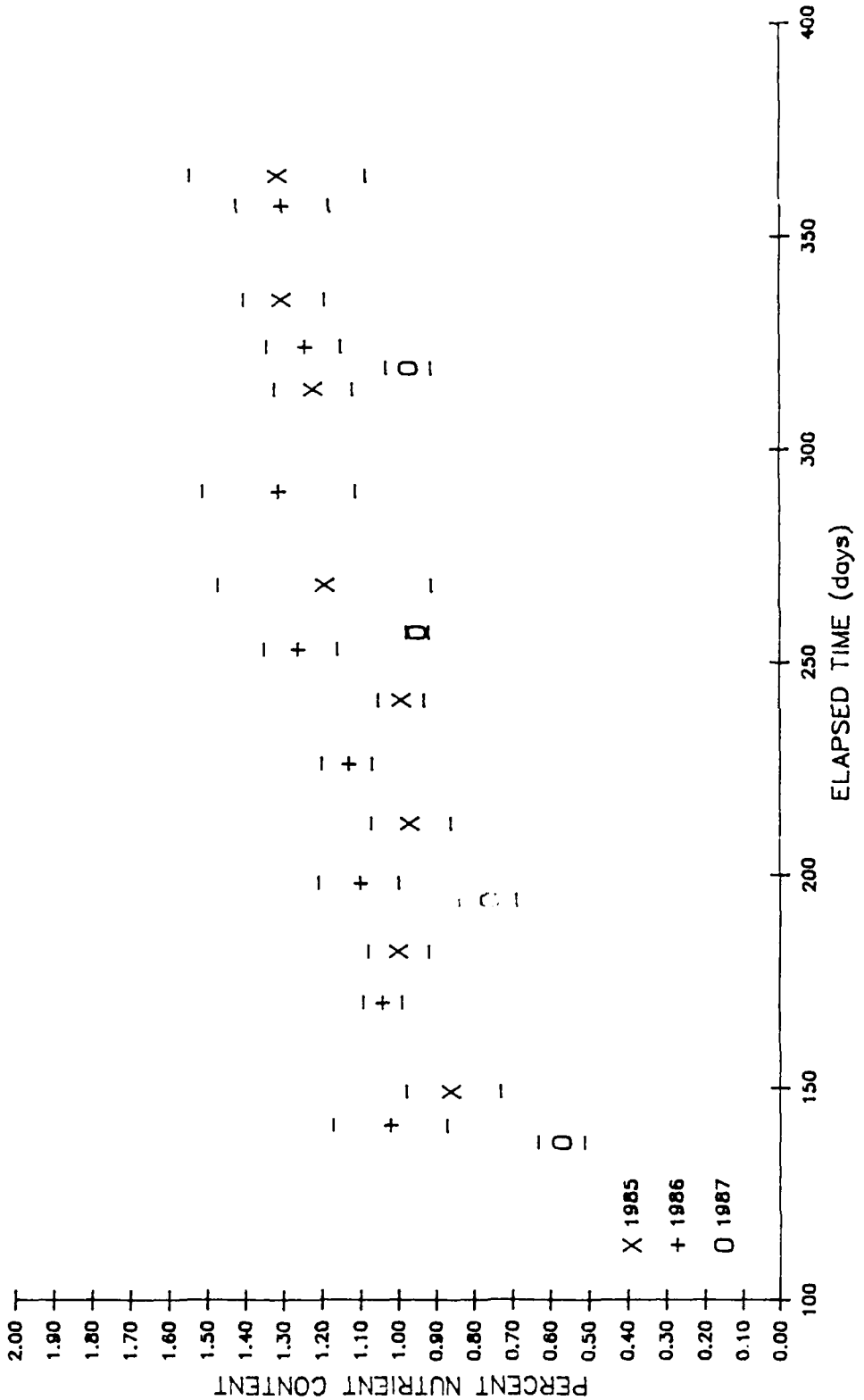

FIGURE 139. Percent nitrogen content of bulk maple leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

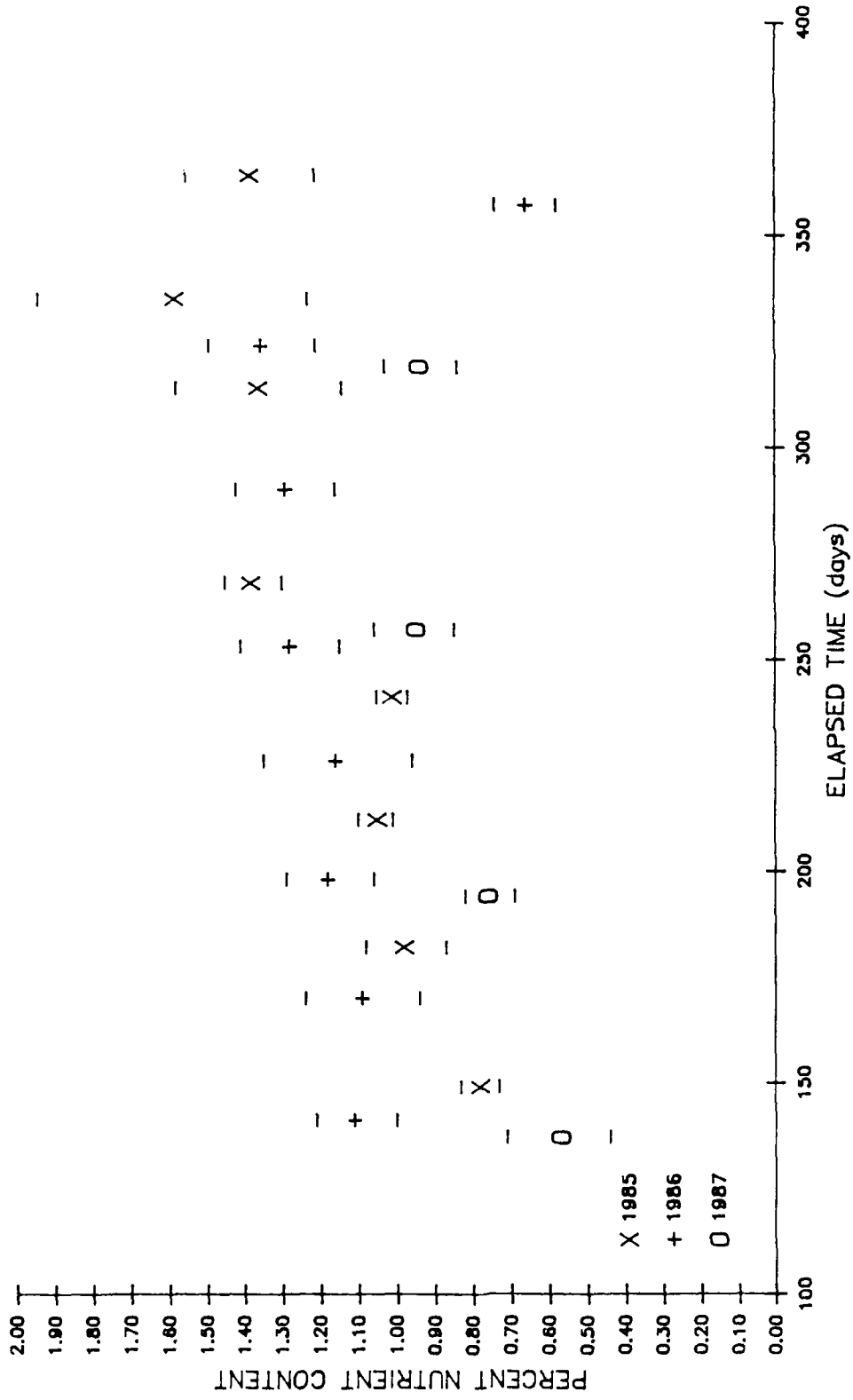

FIGURE 140. Percent nitrogen content of bulk maple leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

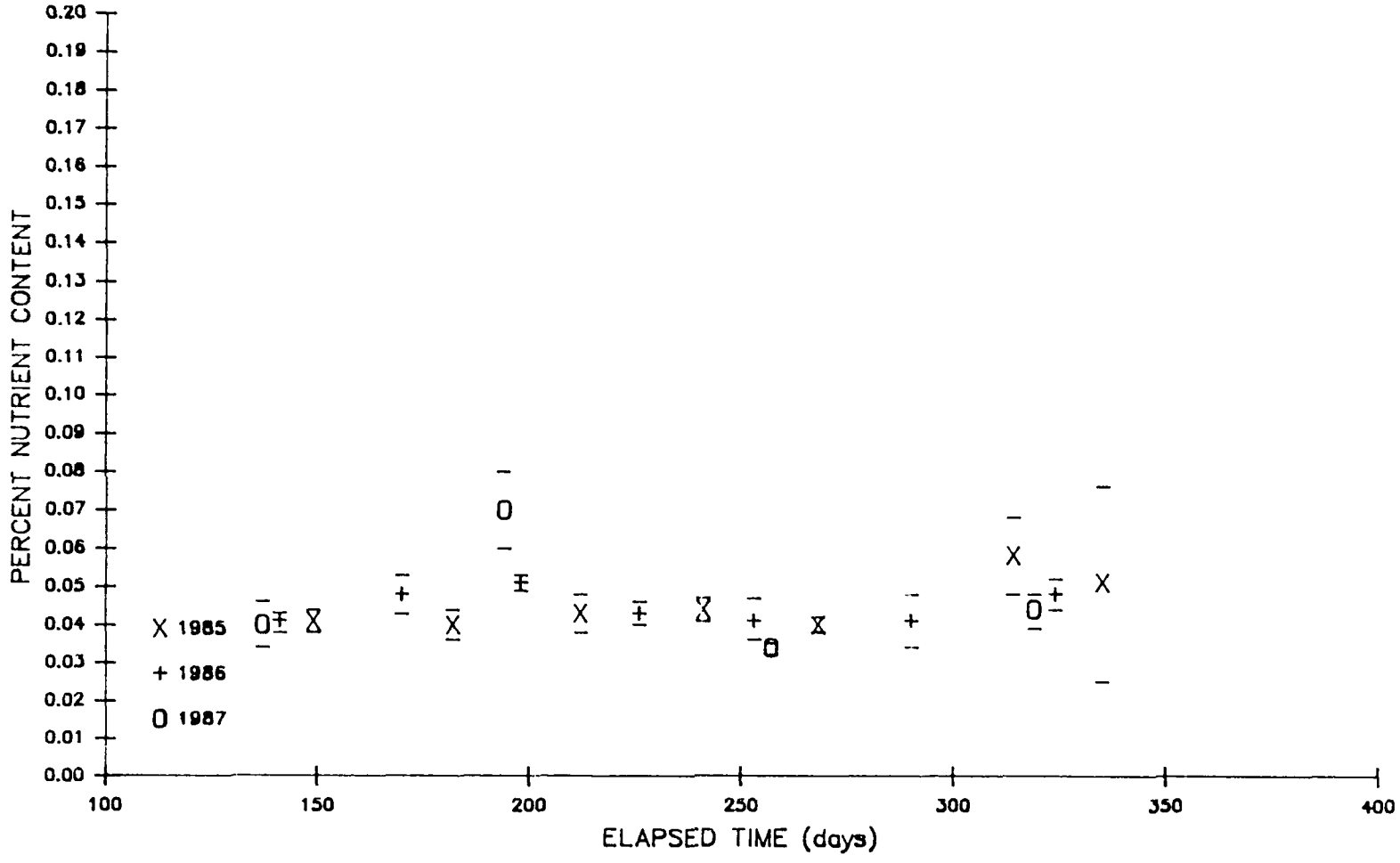

FIGURE 141. Percent phosphorus content of bulk pine needle samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

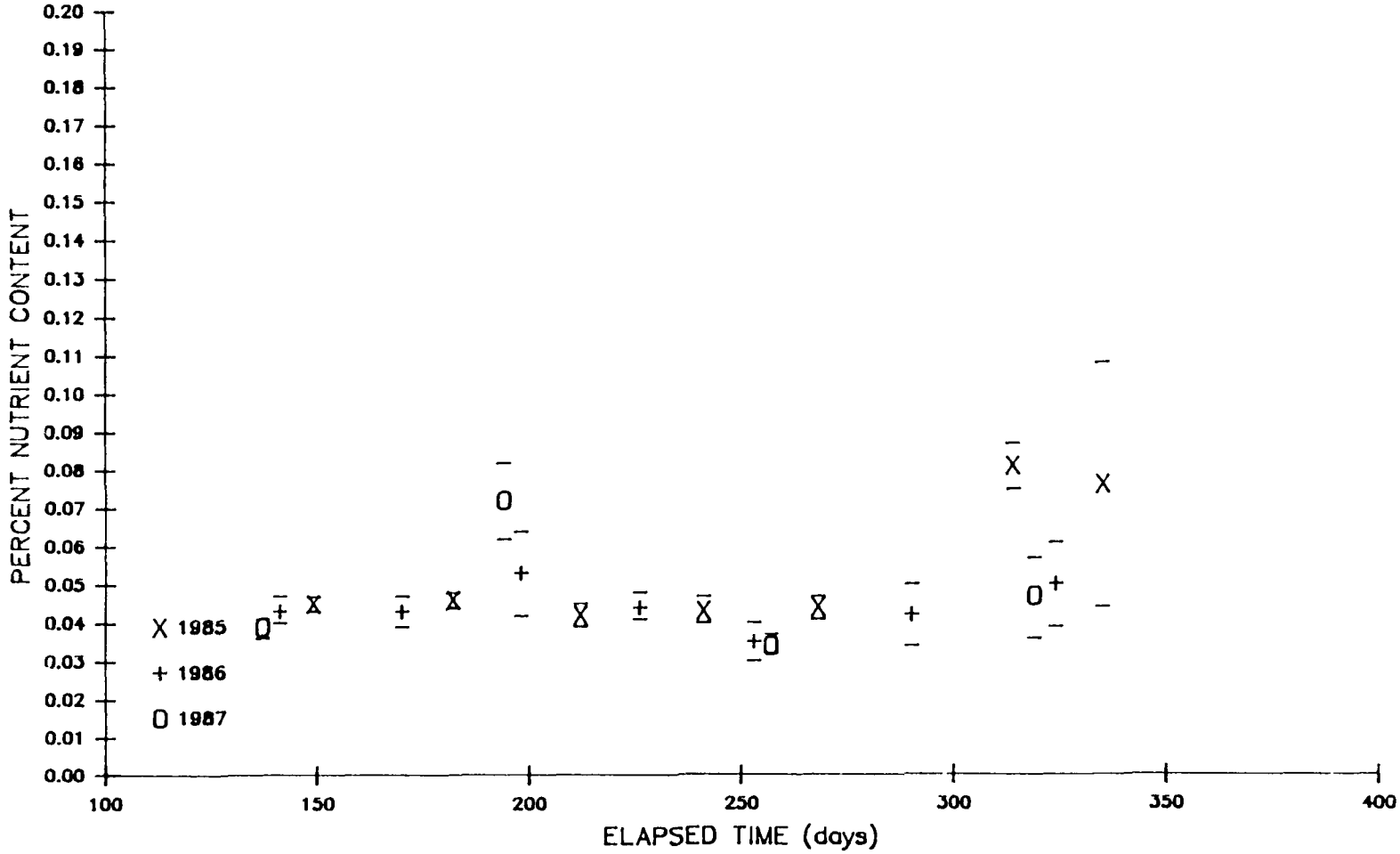

FIGURE 142. Percent phosphorus content of bulk pine needle samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

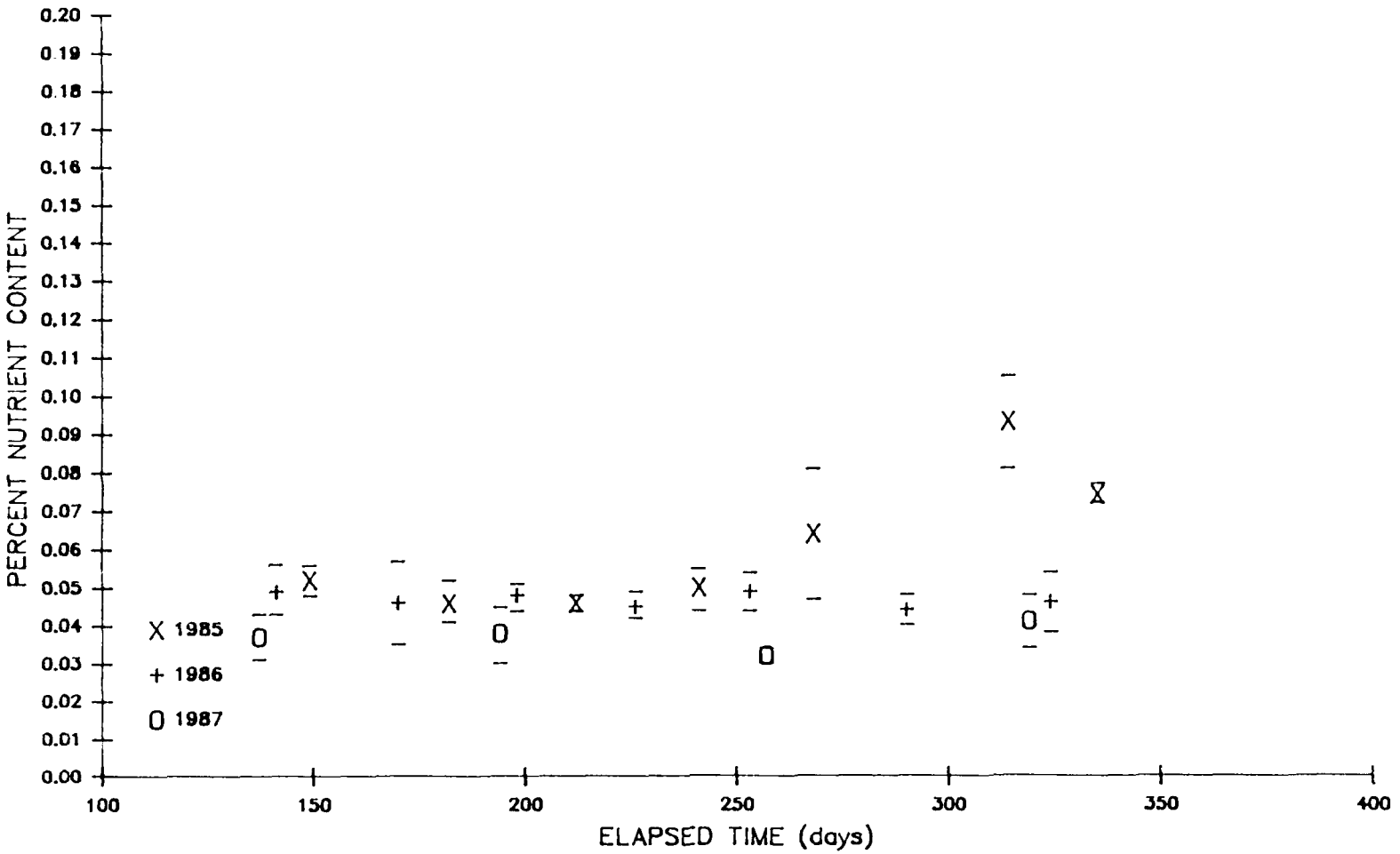

FIGURE 143. Percent phosphorus content of bulk pine needle samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

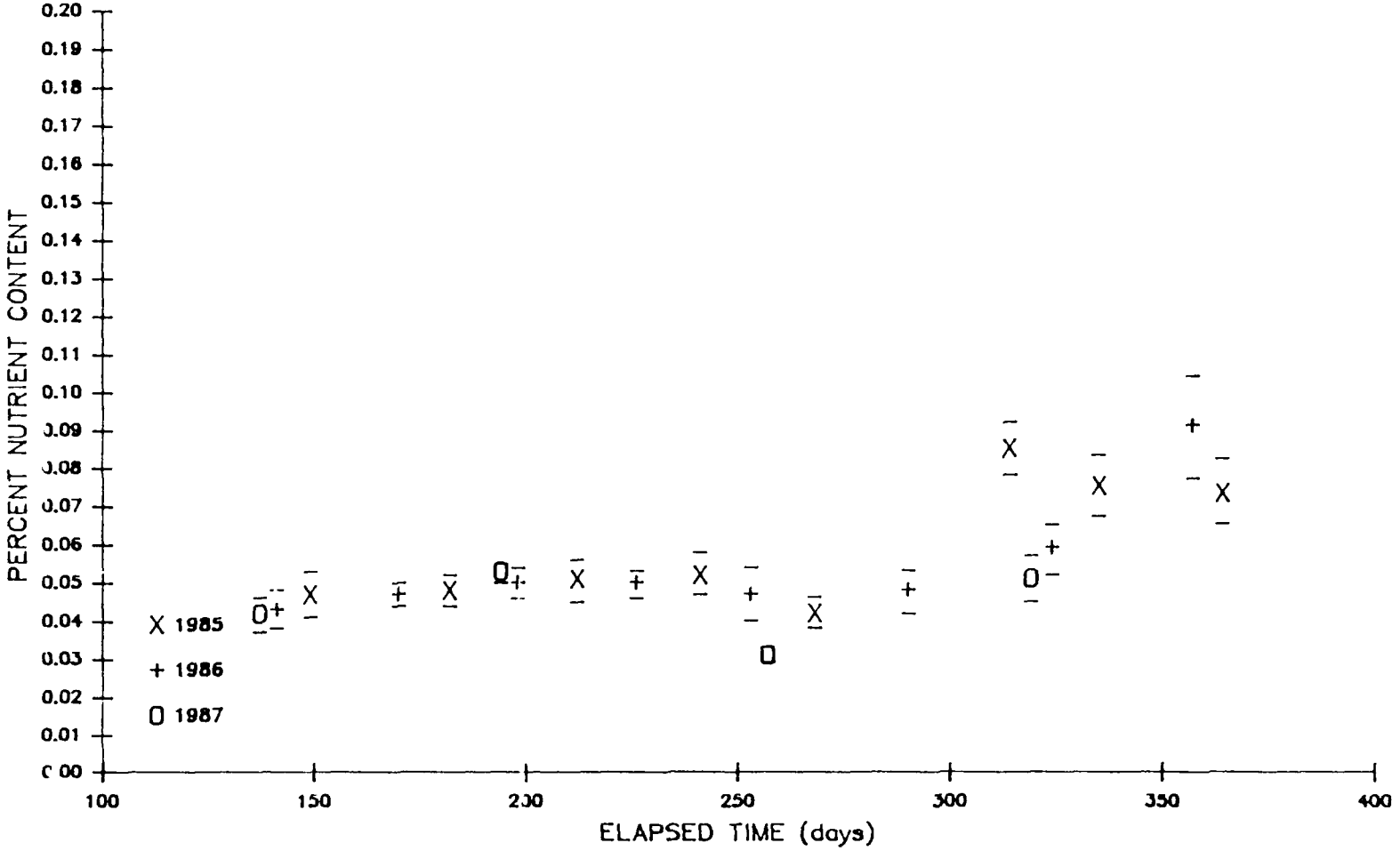

FIGURE 144. Percent phosphorus content of bulk pine needle samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

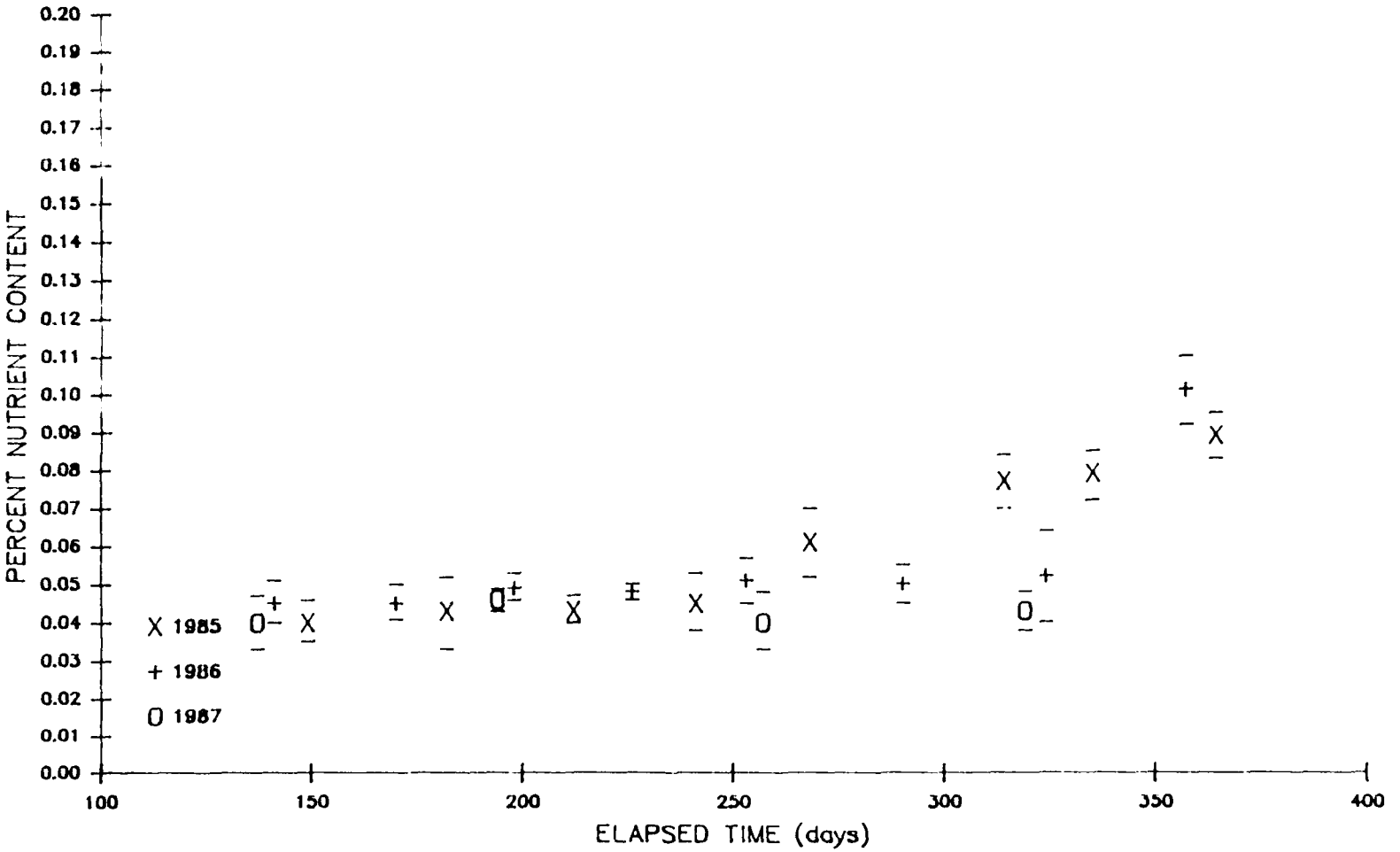

FIGURE 145. Percent phosphorus content of bulk pine needle samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

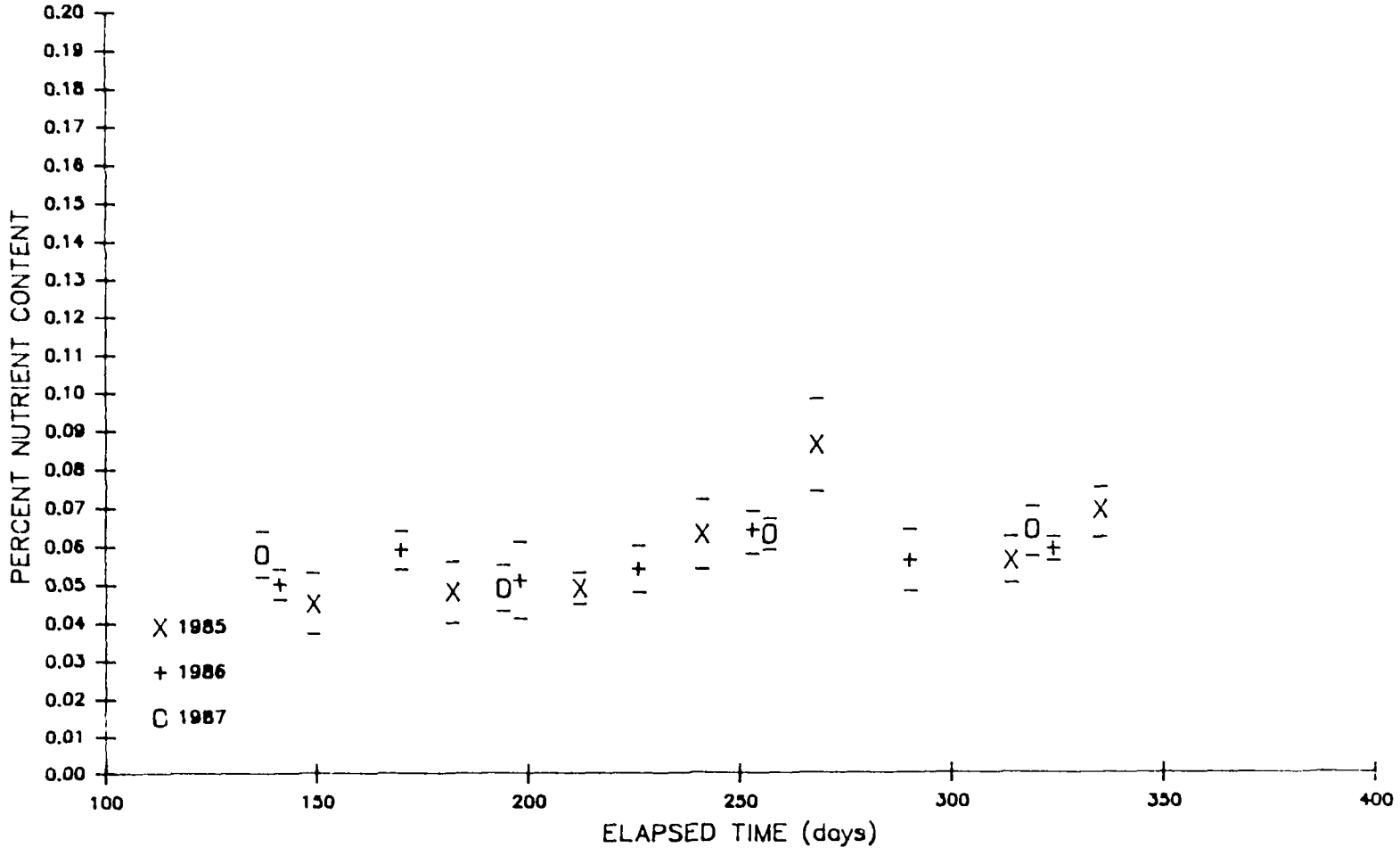

FIGURE 146. Percent phosphorus content of bulk oak leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

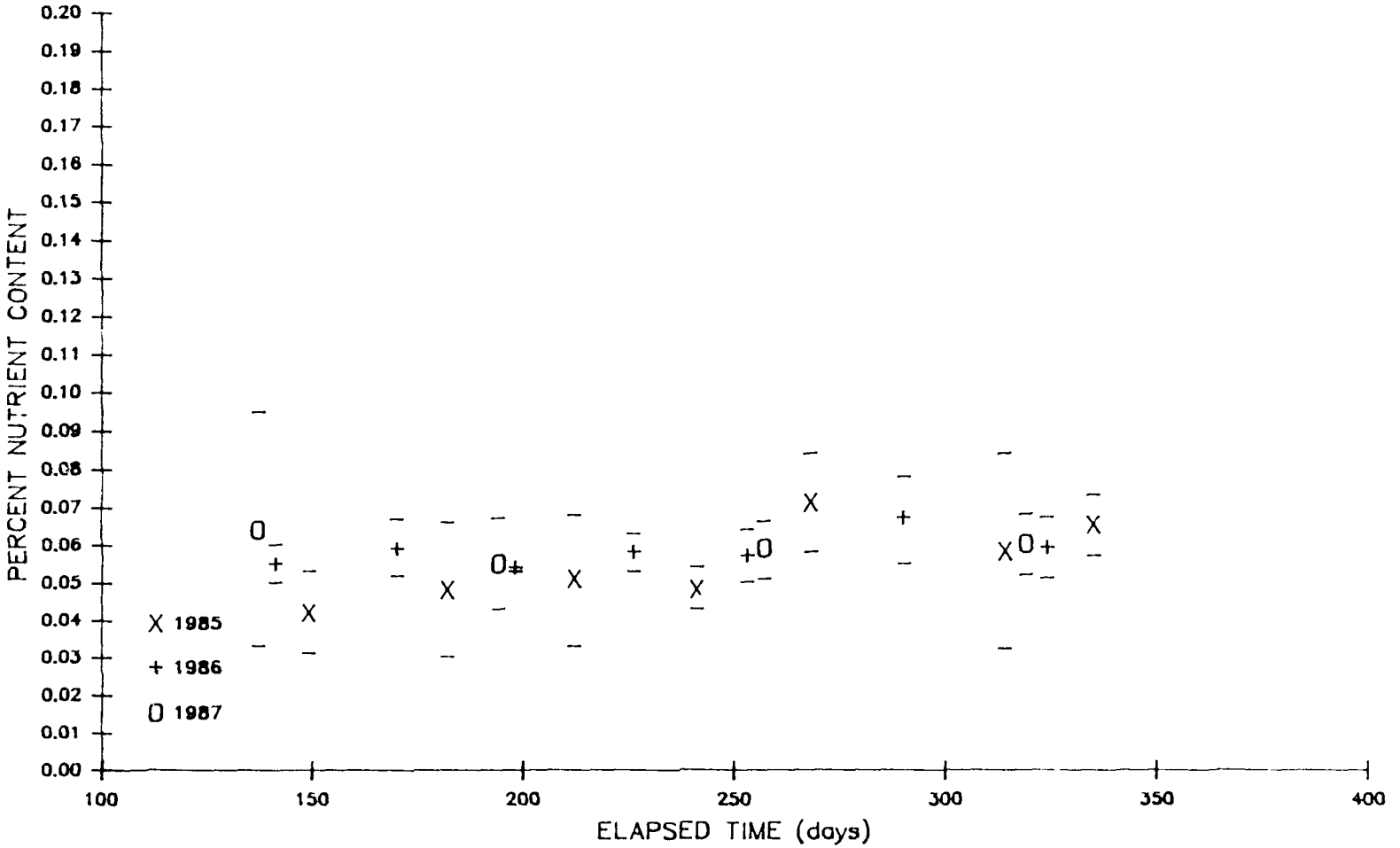

FIGURE 147. Percent phosphorus content of bulk oak leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

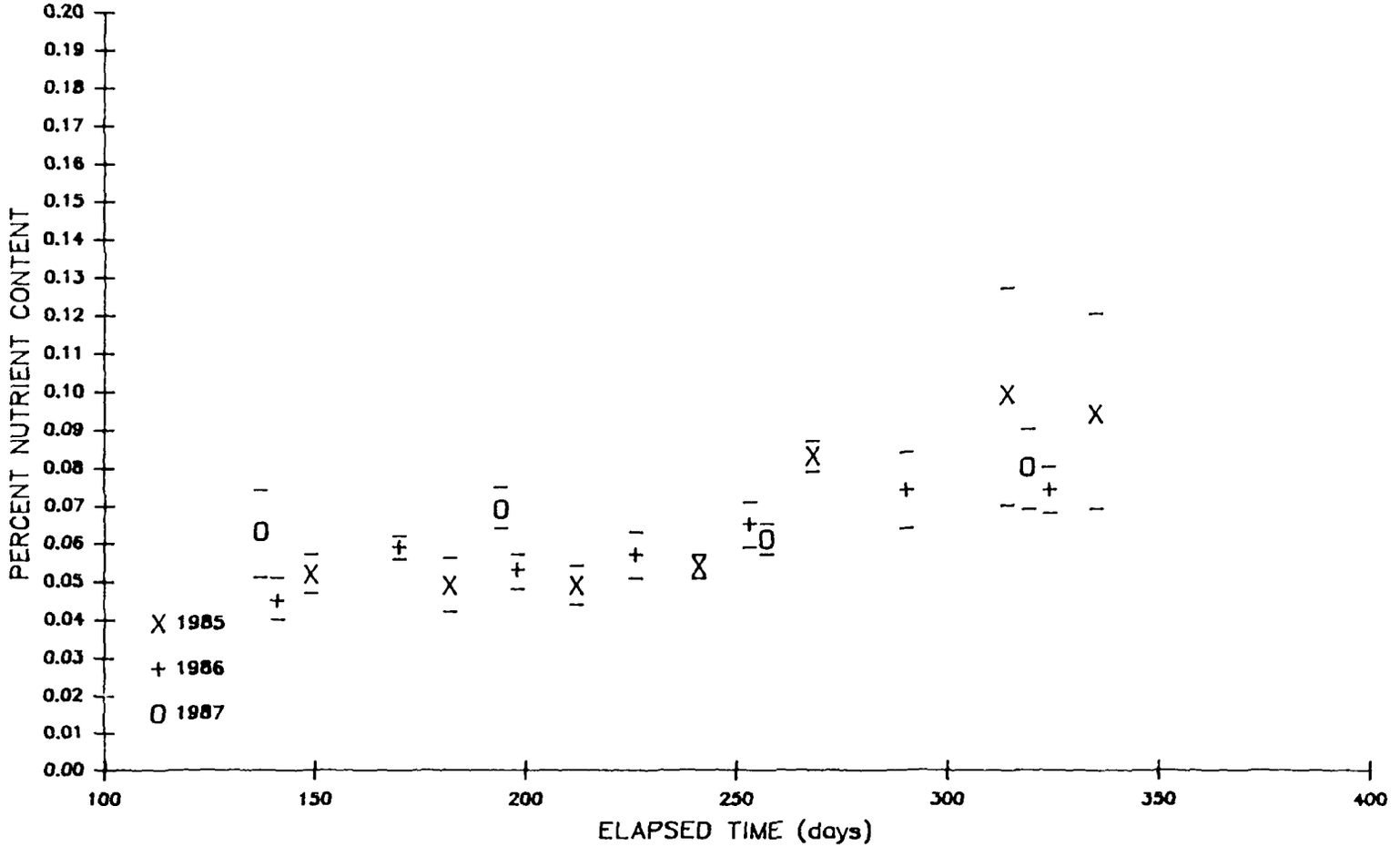

FIGURE 148. Percent phosphorus content of bulk oak leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

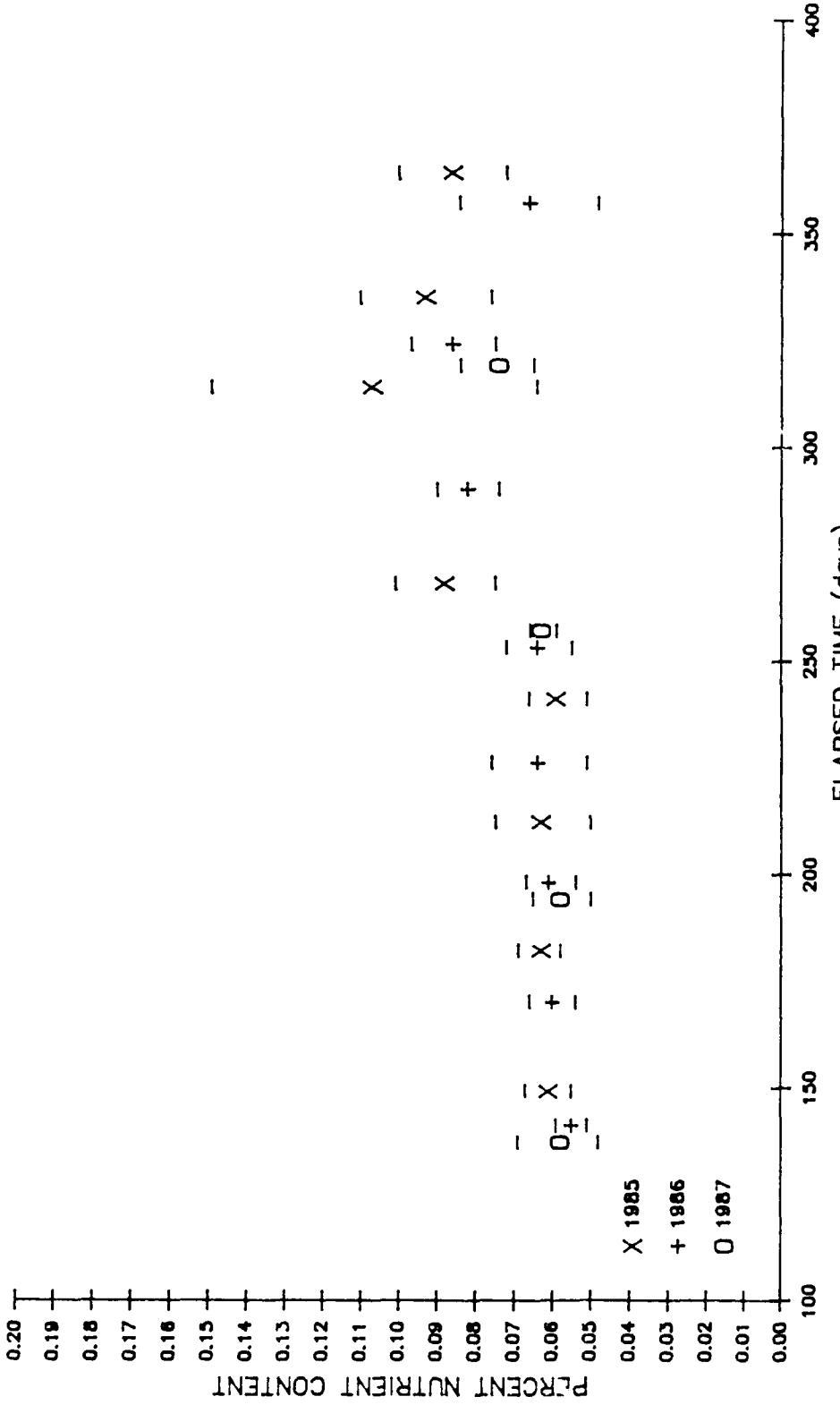

FIGURE 149. Percent phosphorus content of bulk oak leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

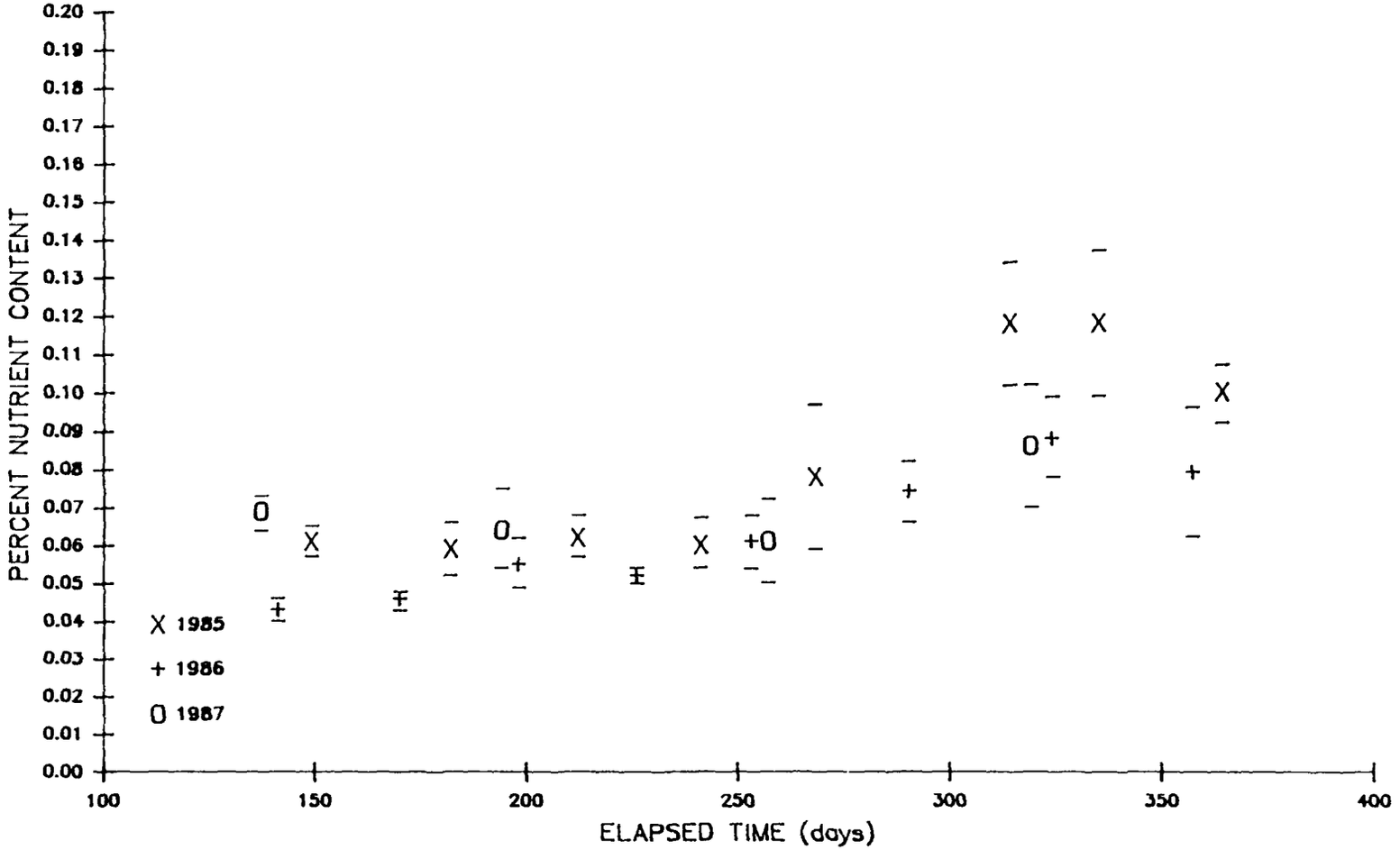

FIGURE 150. Percent phosphorus content of bulk oak leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

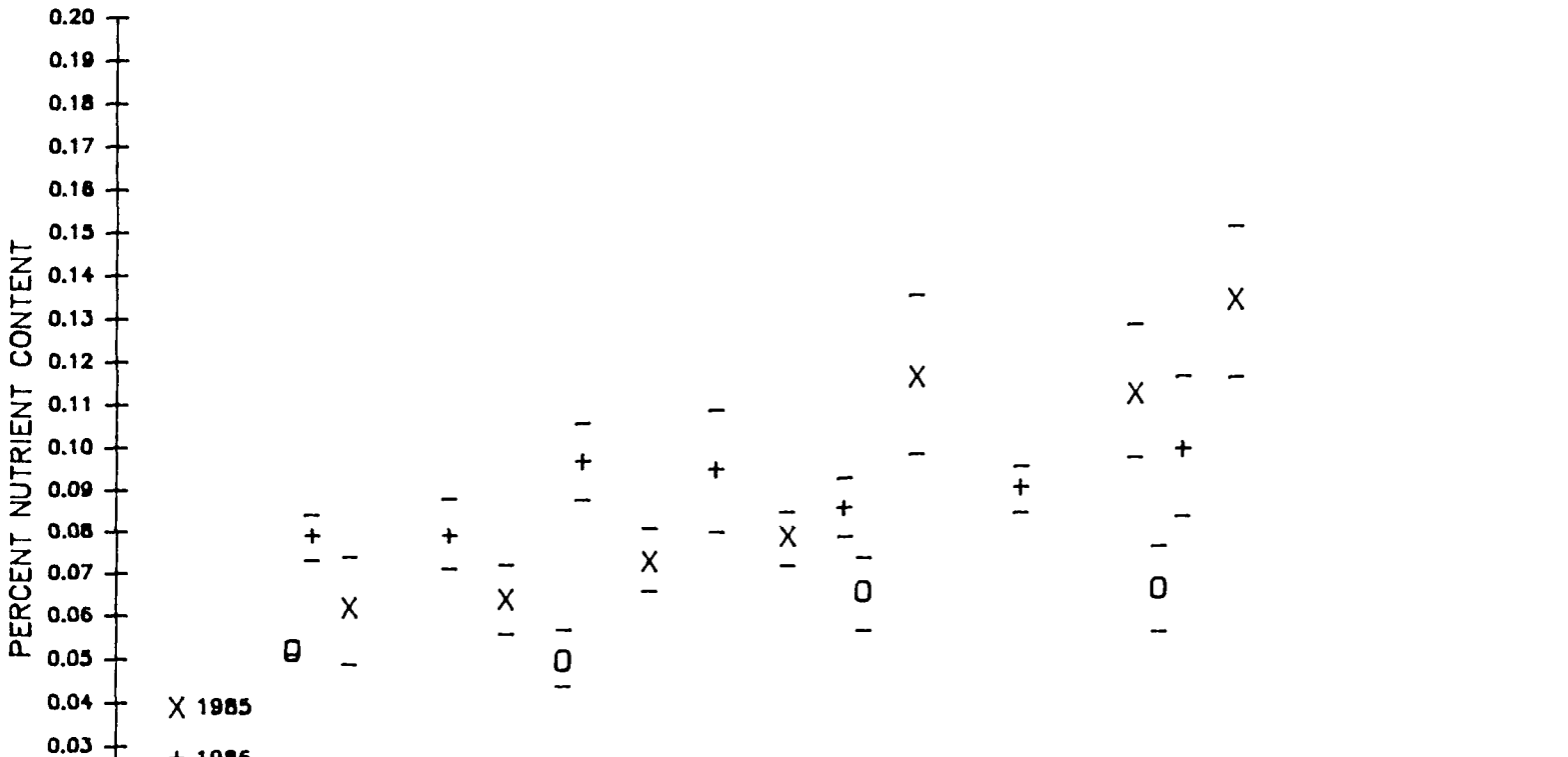

FIGURE 151. Percent phosphorus content of bulk maple leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

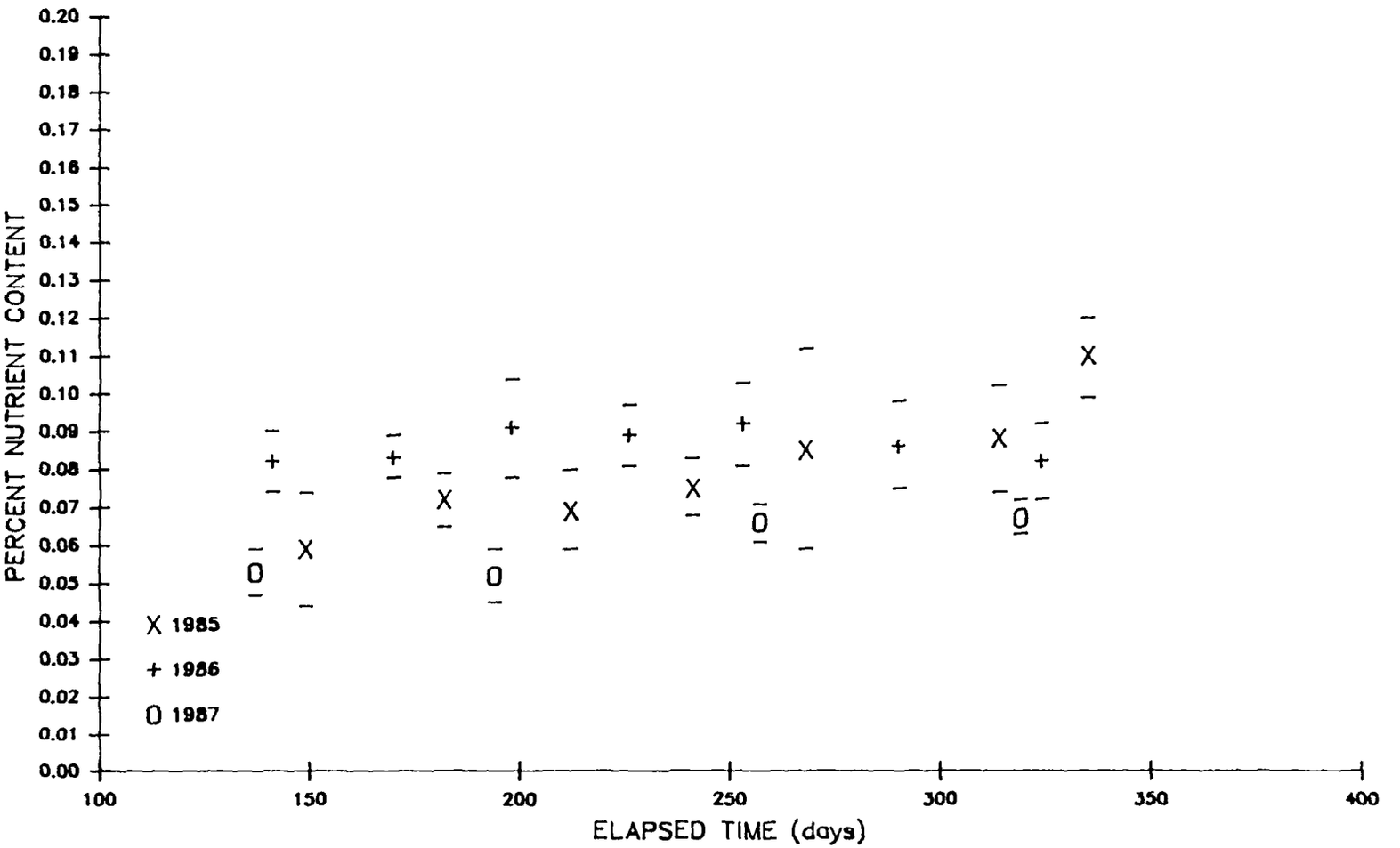

FIGURE 152. Percent phosphorus content of bulk maple leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

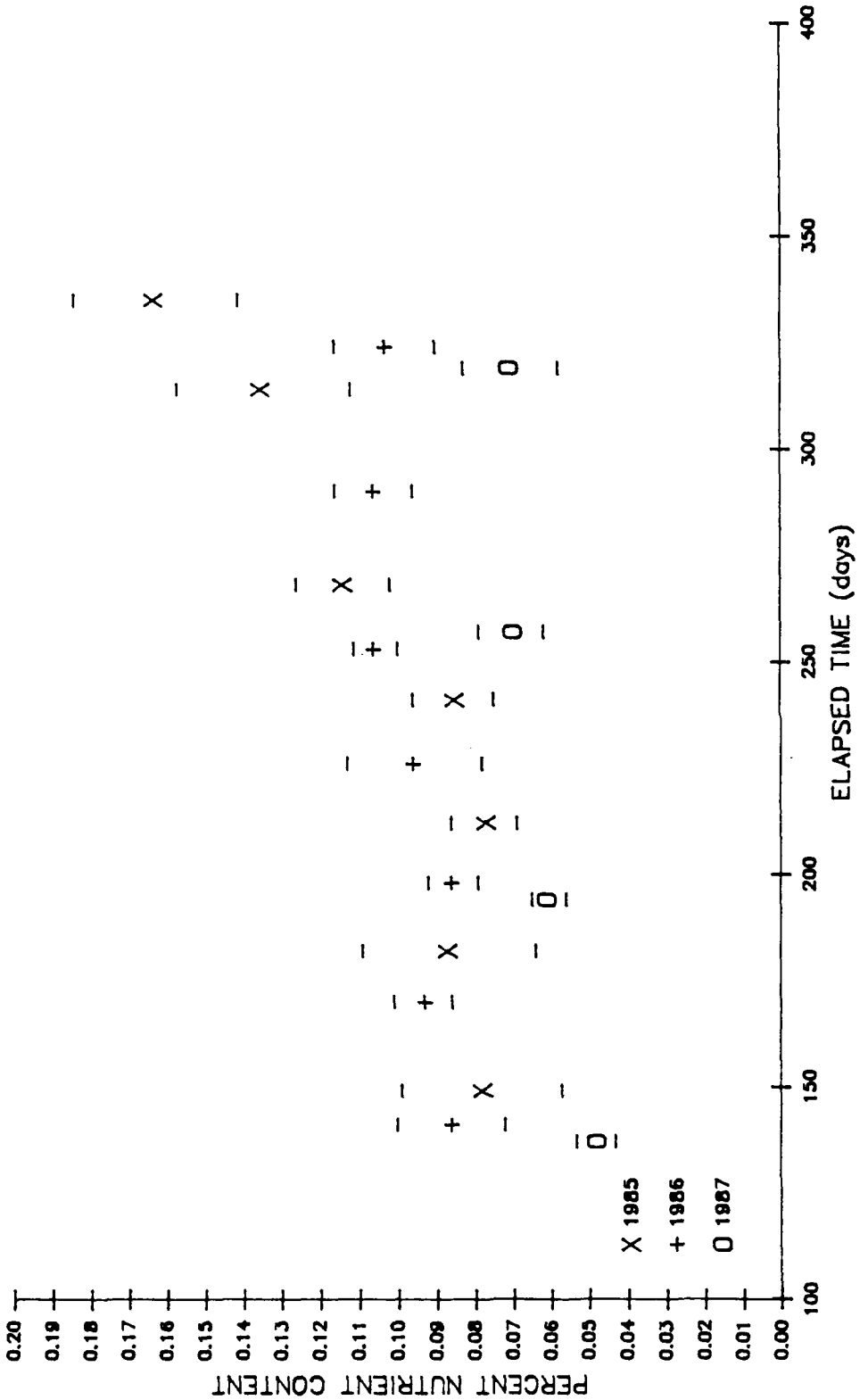

FIGURE 153. Percent phosphorus content of bulk maple leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

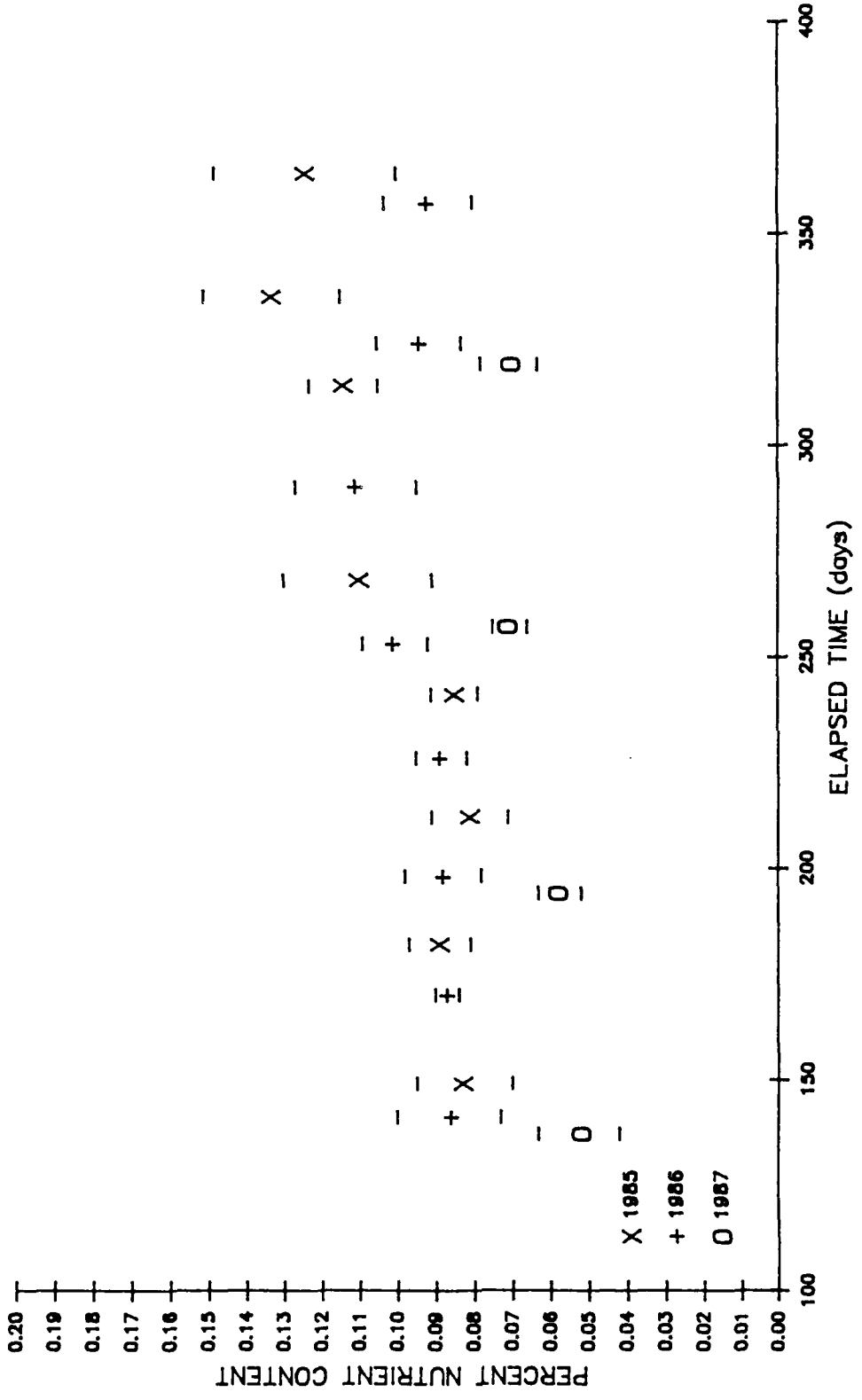

FIGURE 154. Percent phosphorus content of bulk maple leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

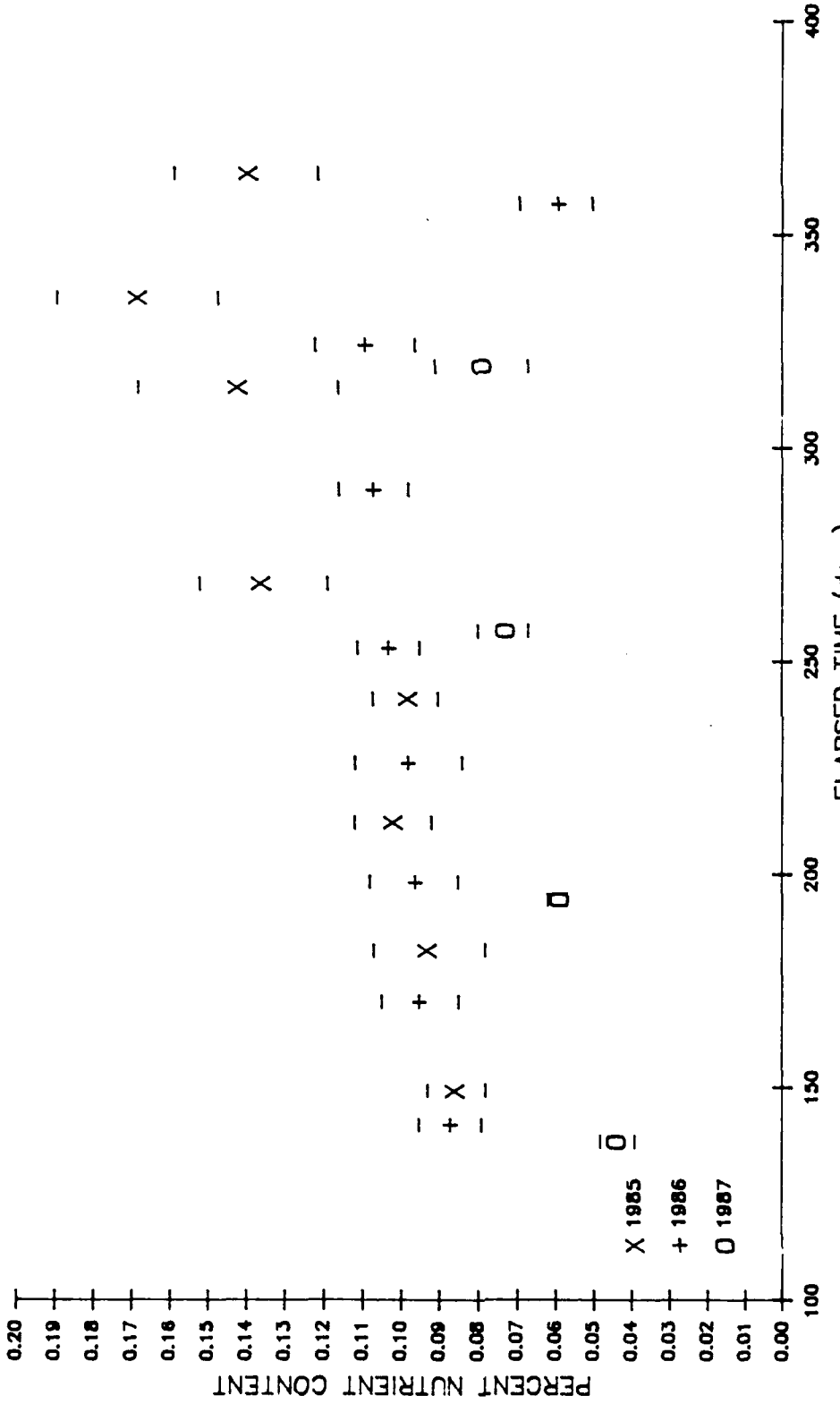

FIGURE 155. Percent phosphorus content of bulk maple leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

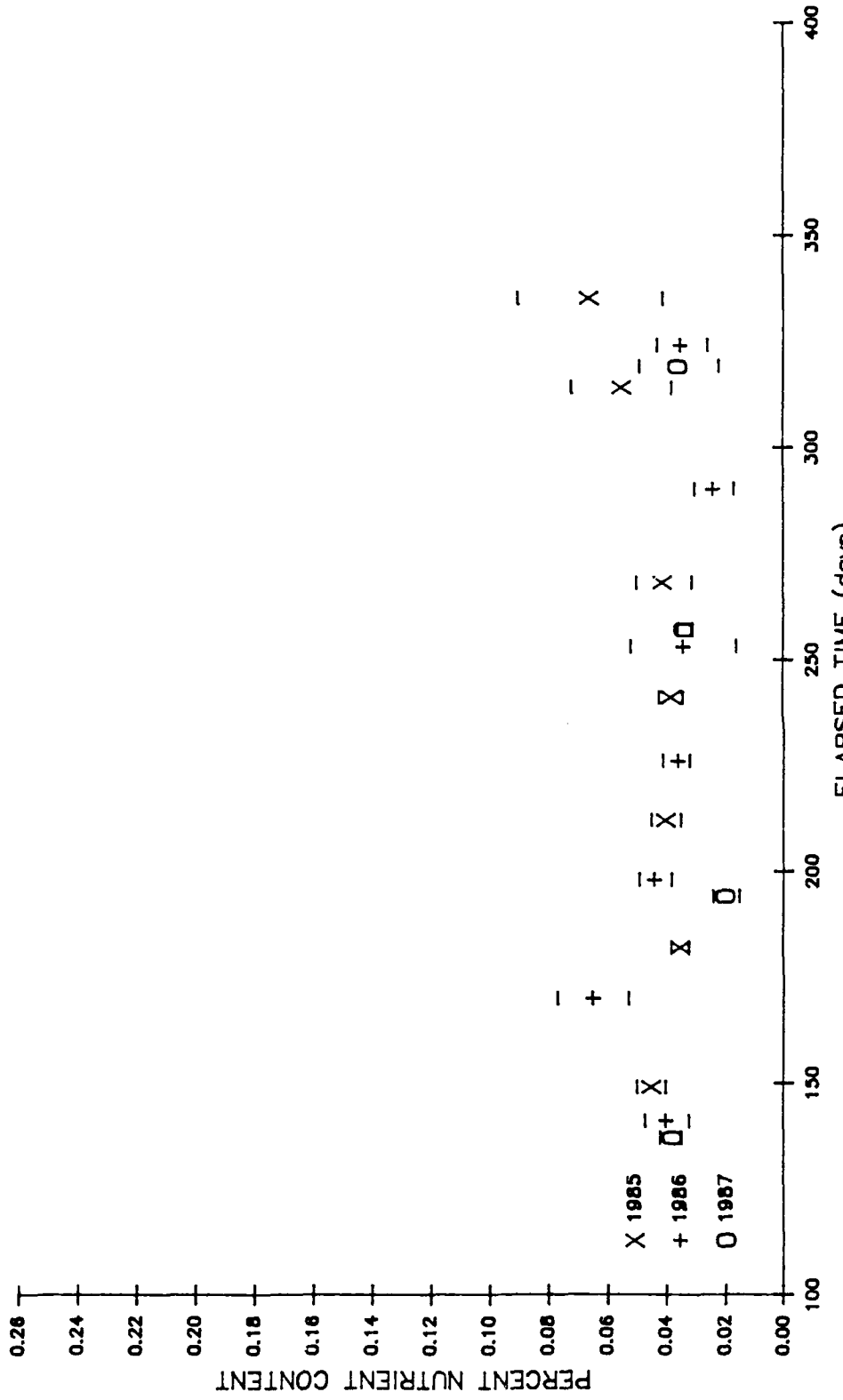

FIG. 156. Percent potassium content of bulk pine needle samples retrieved from the ground unit plot location during the 1984–1985, 1985–1986, and 1986–1987 experiments.

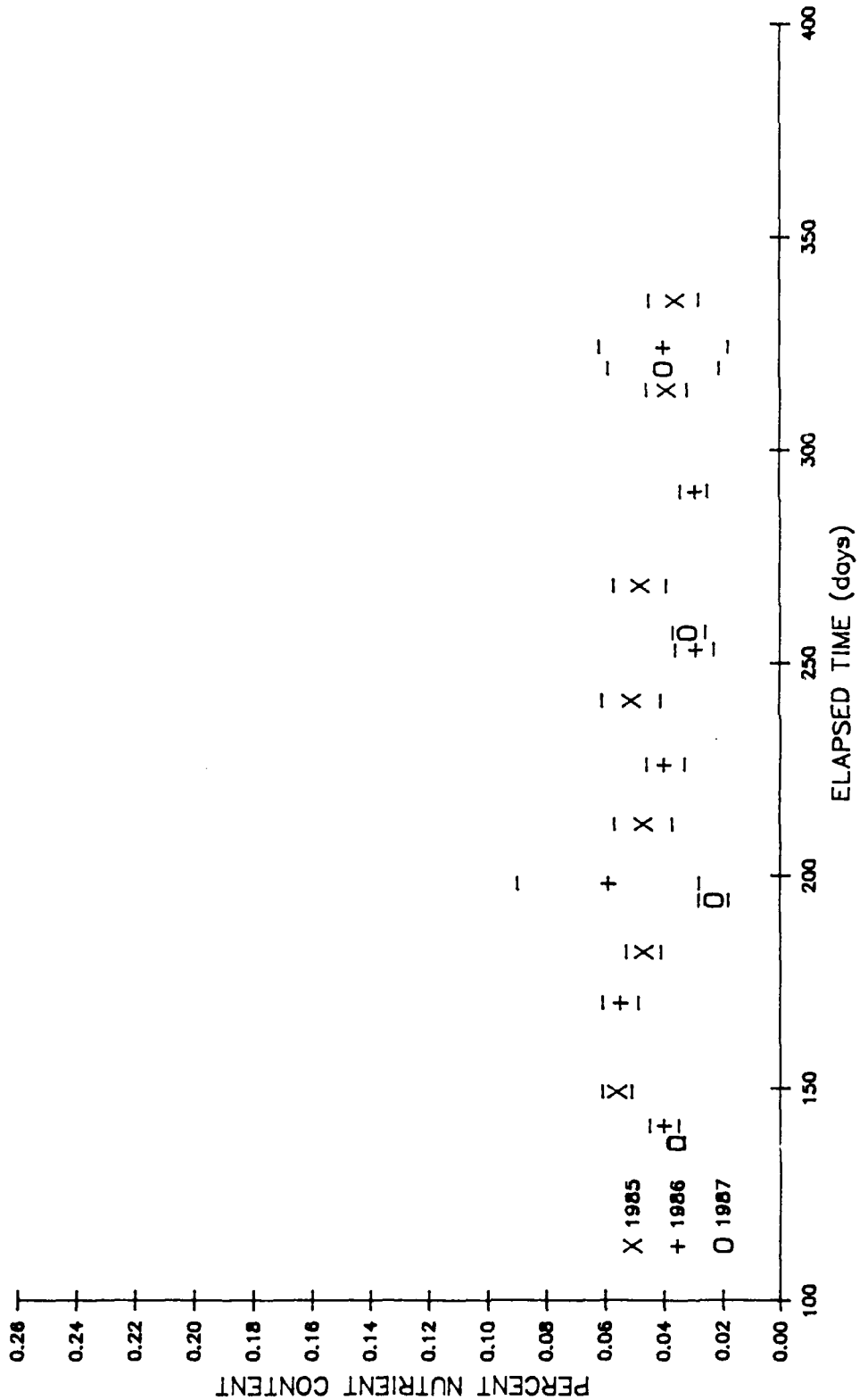

FIGURE 157. Percent potassium content of bulk pine needle samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

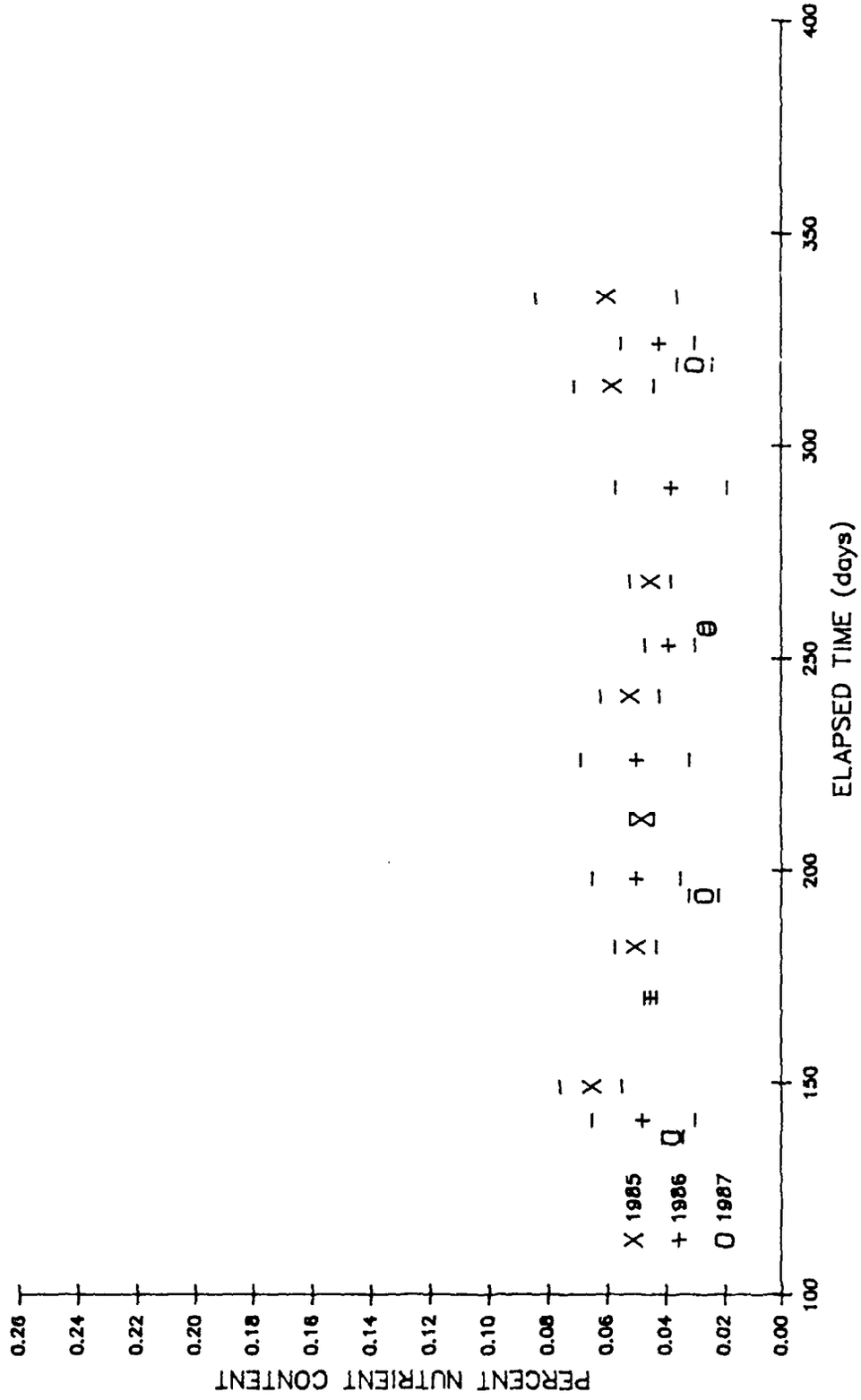

FIGURE 158. Percent potassium content of bulk pine needle samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

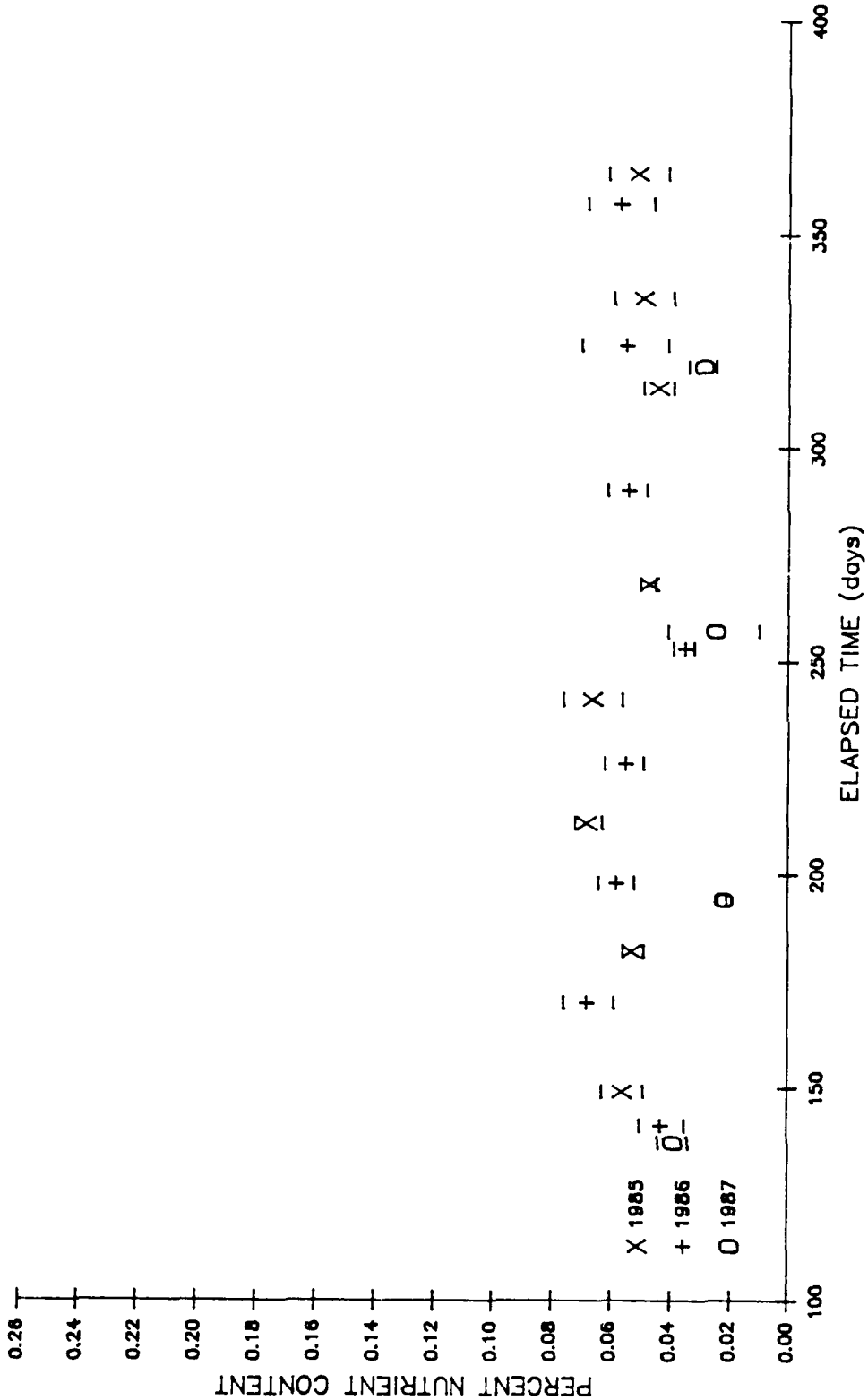

FIGURE 159. Percent potassium content of bulk pine needle samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

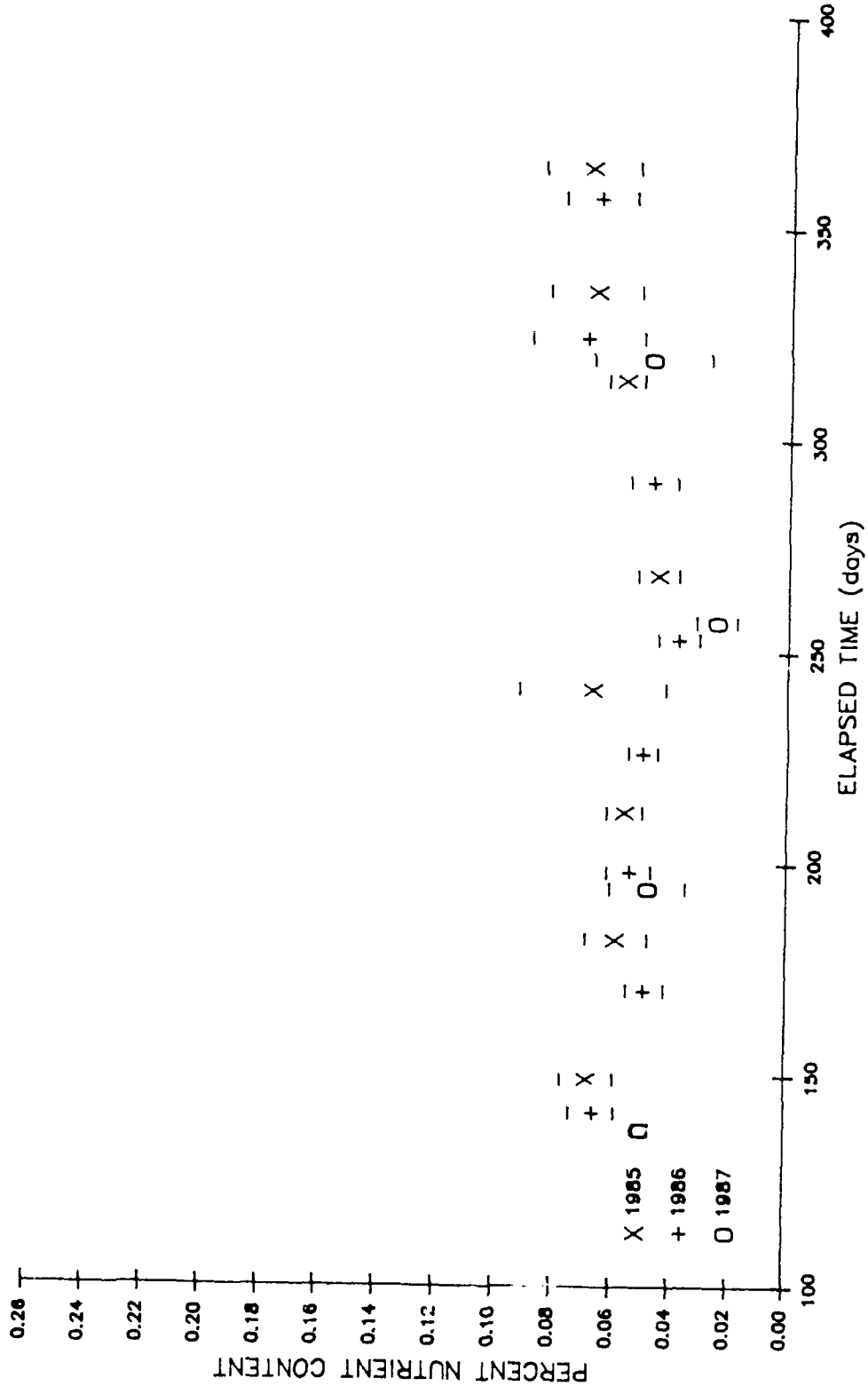

FIGURE 160. Percent potassium content of bulk pine needle samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

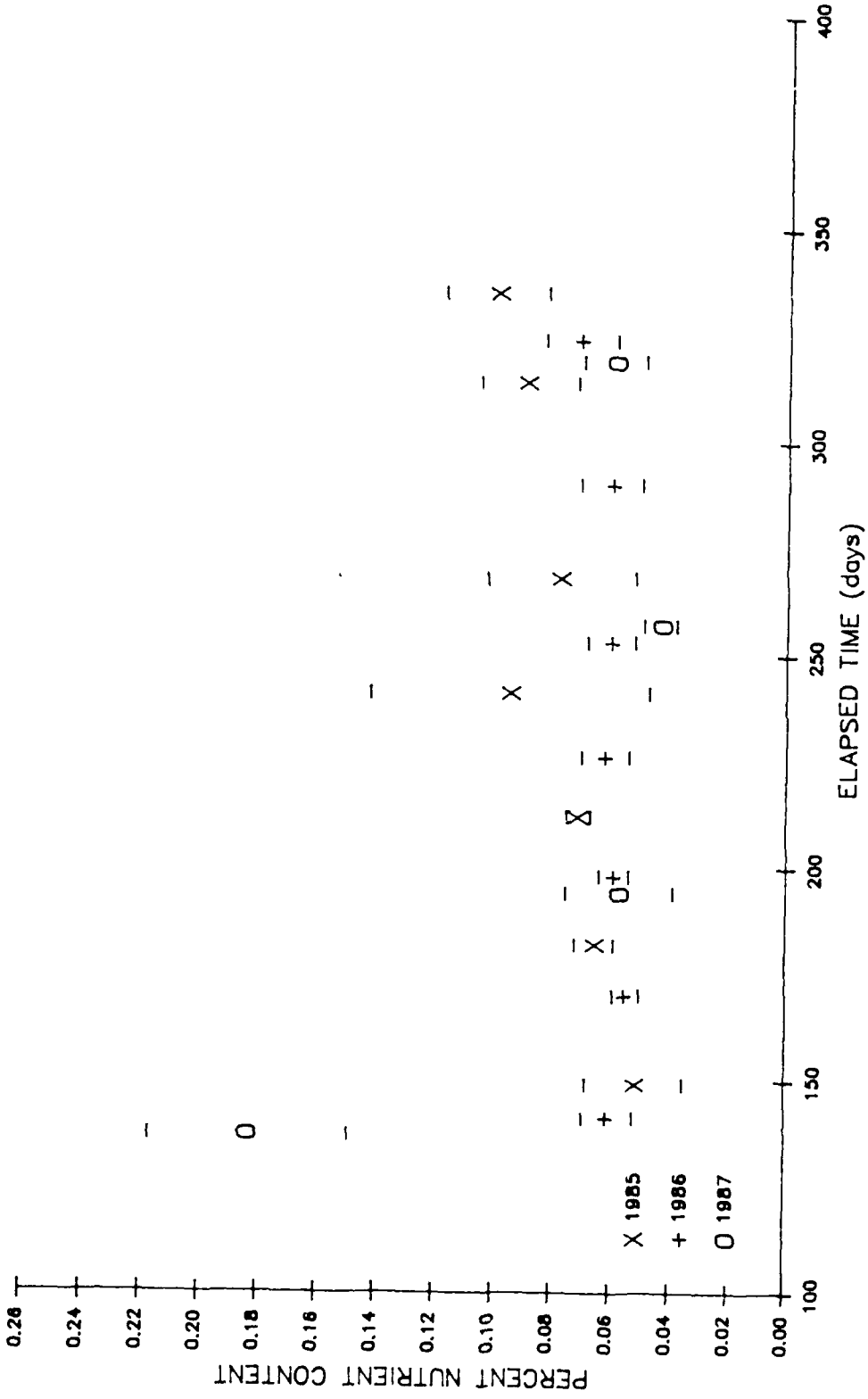

FIGURE 161. Percent potassium content of bulk oak leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

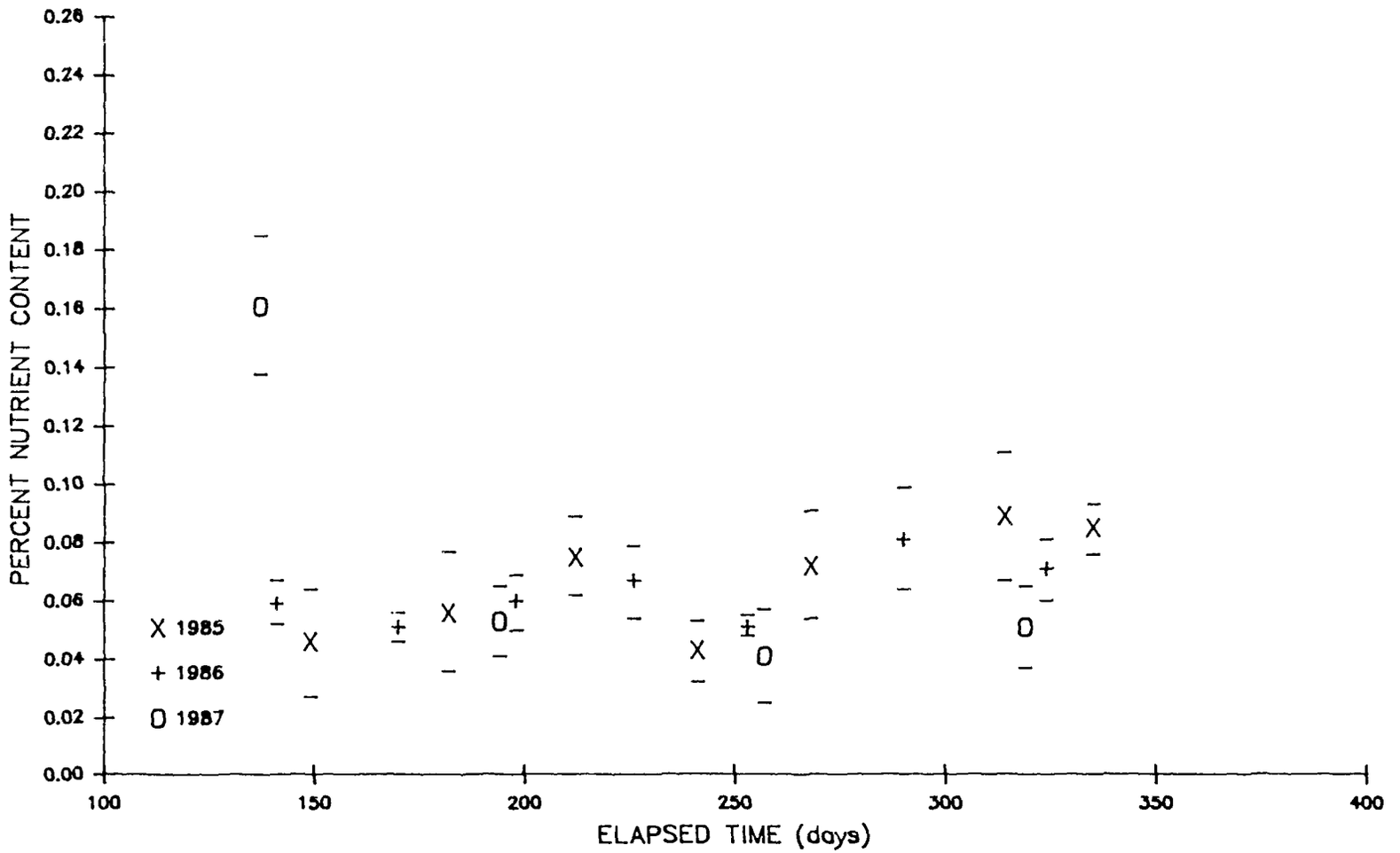

FIGURE 162. Percent potassium content of bulk oak leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

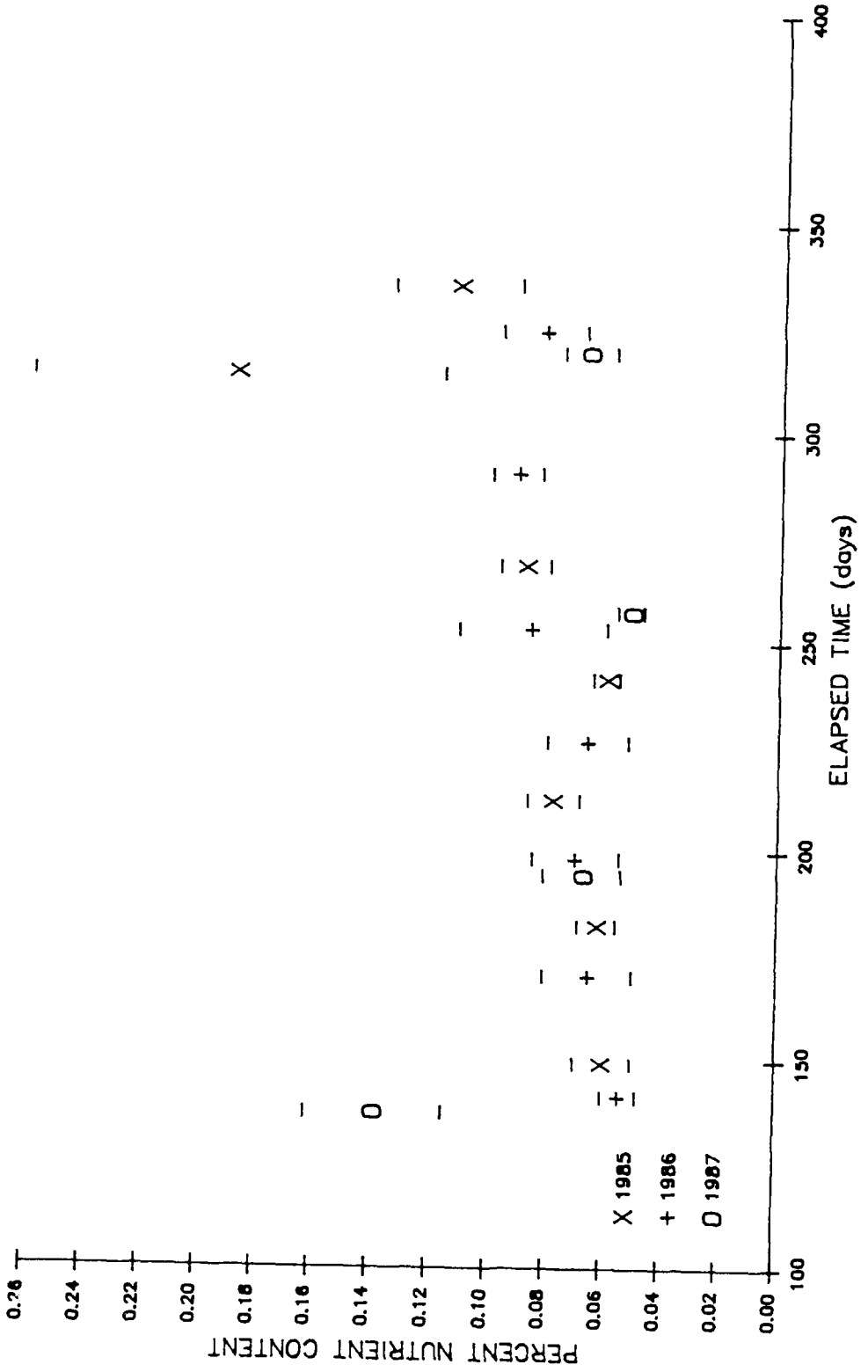

FIGURE 163. Percent potassium content of bulk oak leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

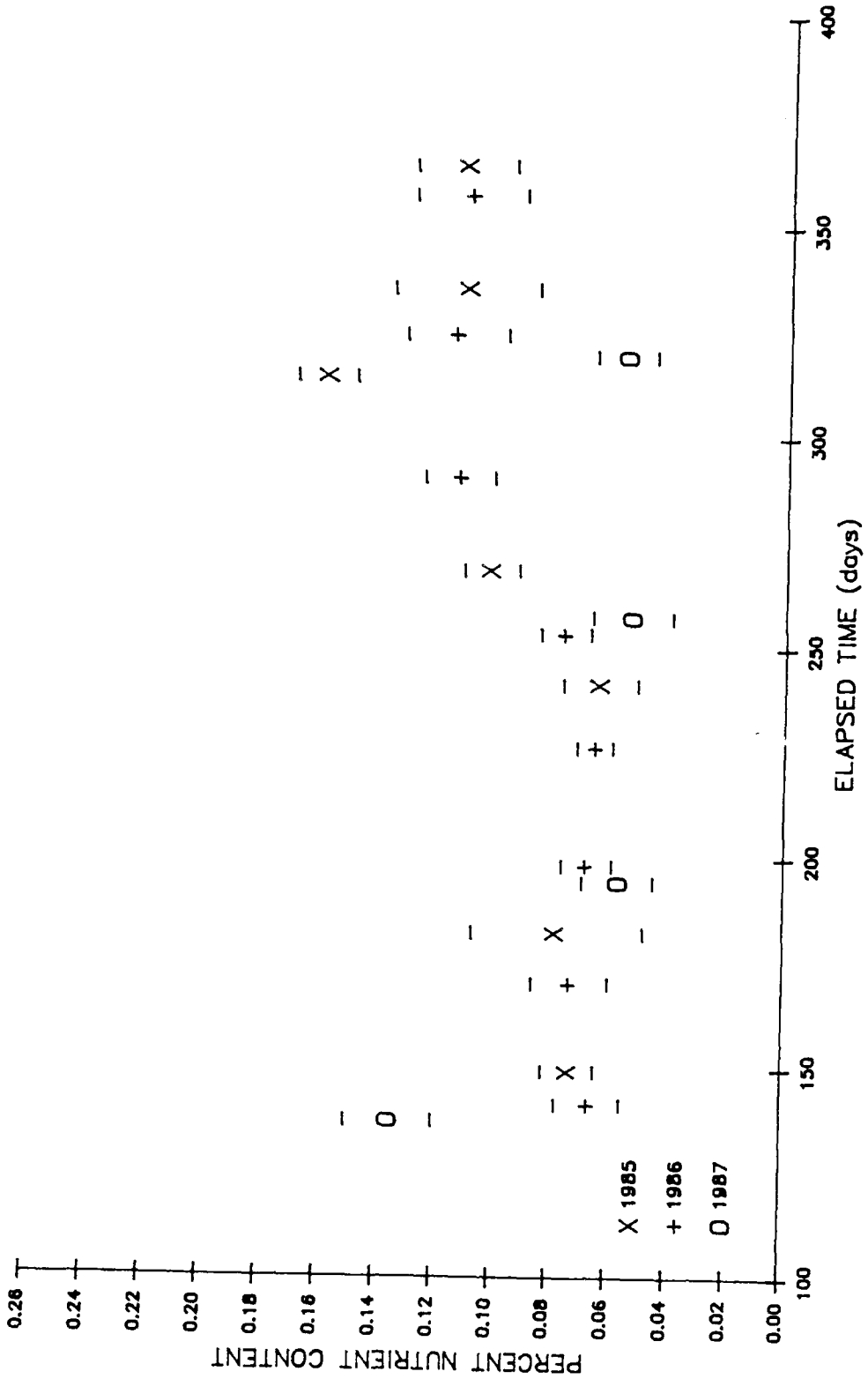

FIGURE 164. Percent potassium content of bulk oak leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

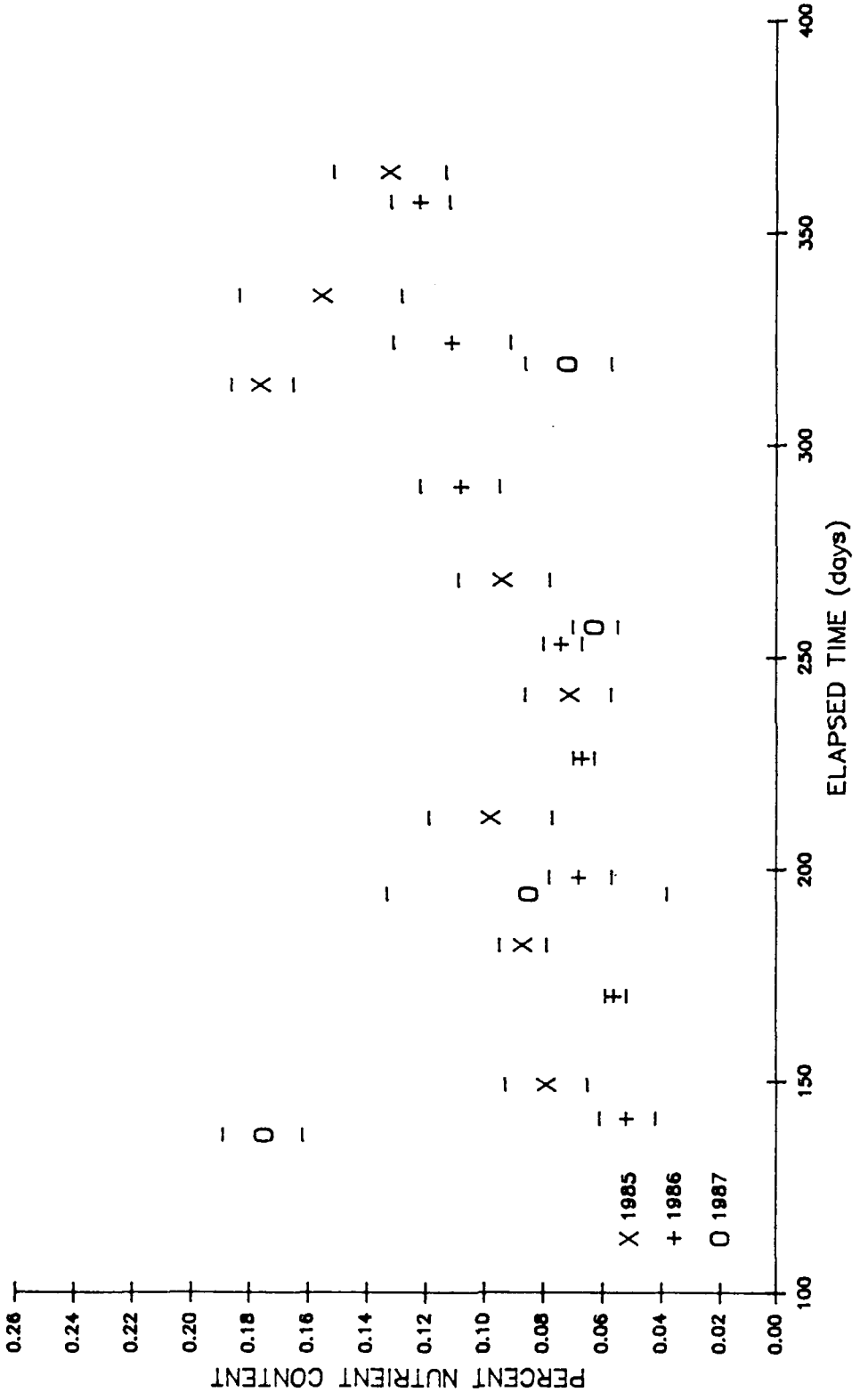

FIGURE 165. Percent potassium content of bulk oak leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

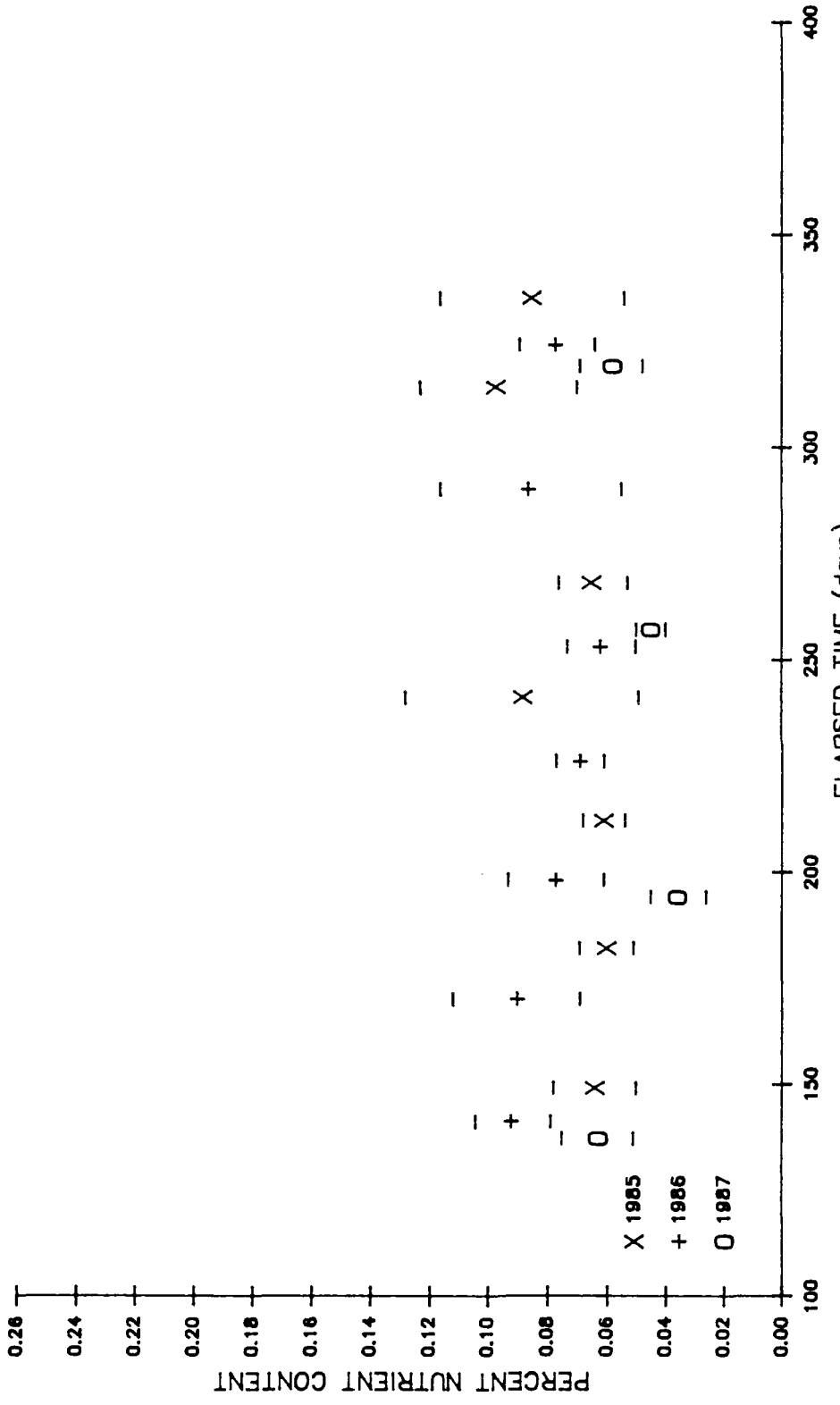

FIGURE 166. Percent potassium content of bulk maple leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

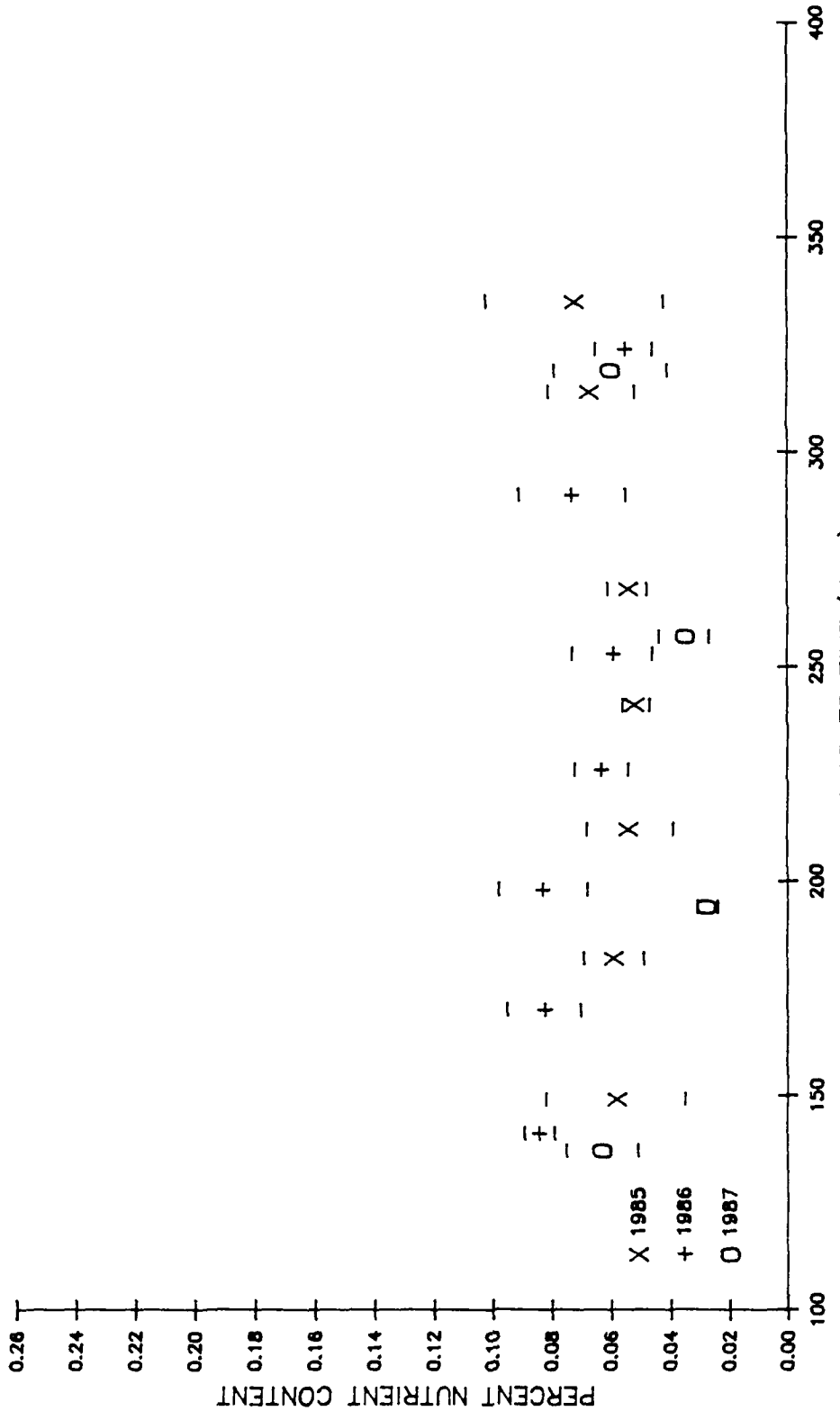

FIGURE 167. Percent potassium content of bulk maple leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

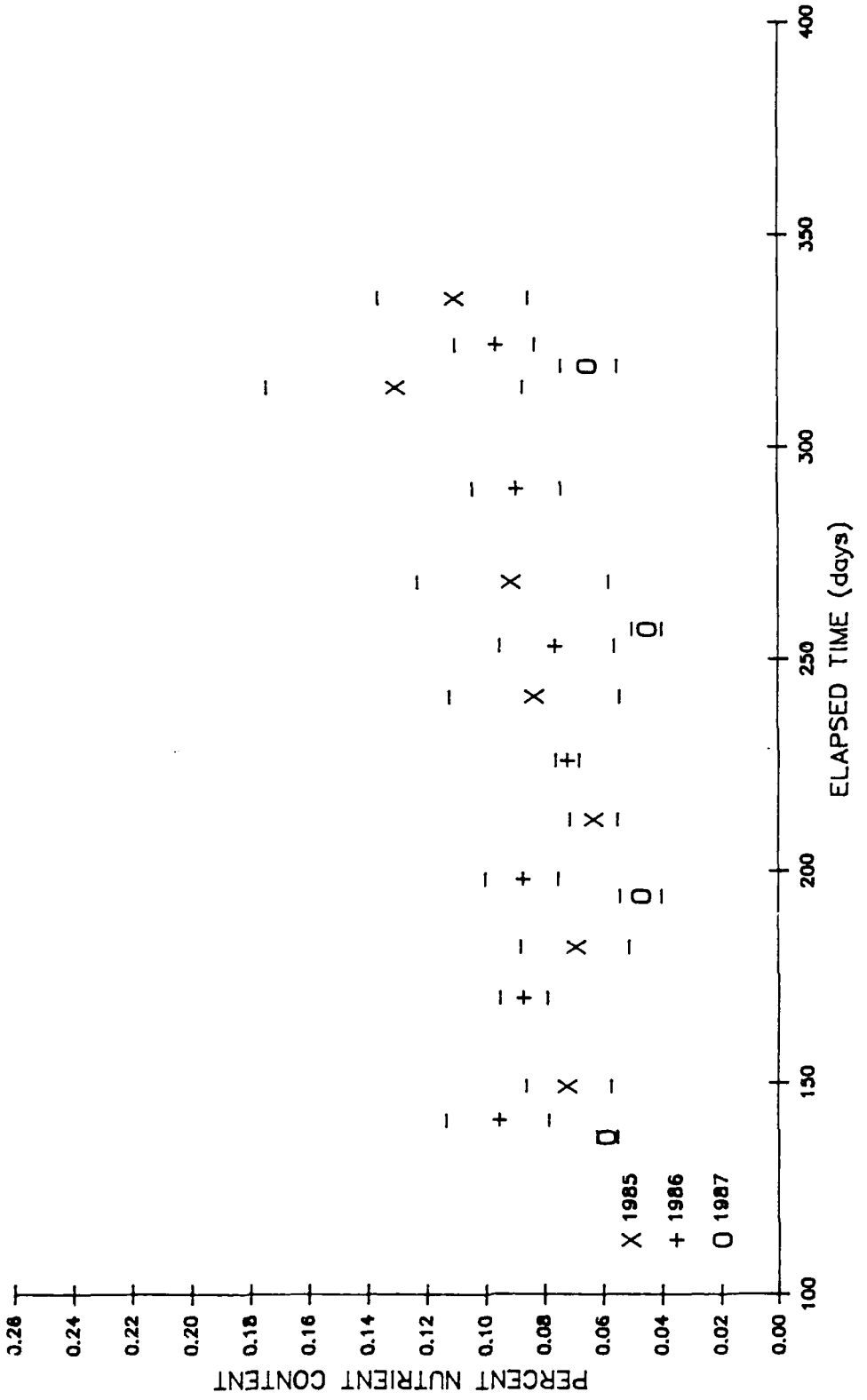

FIGURE 168. Percent potassium content of bulk maple leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

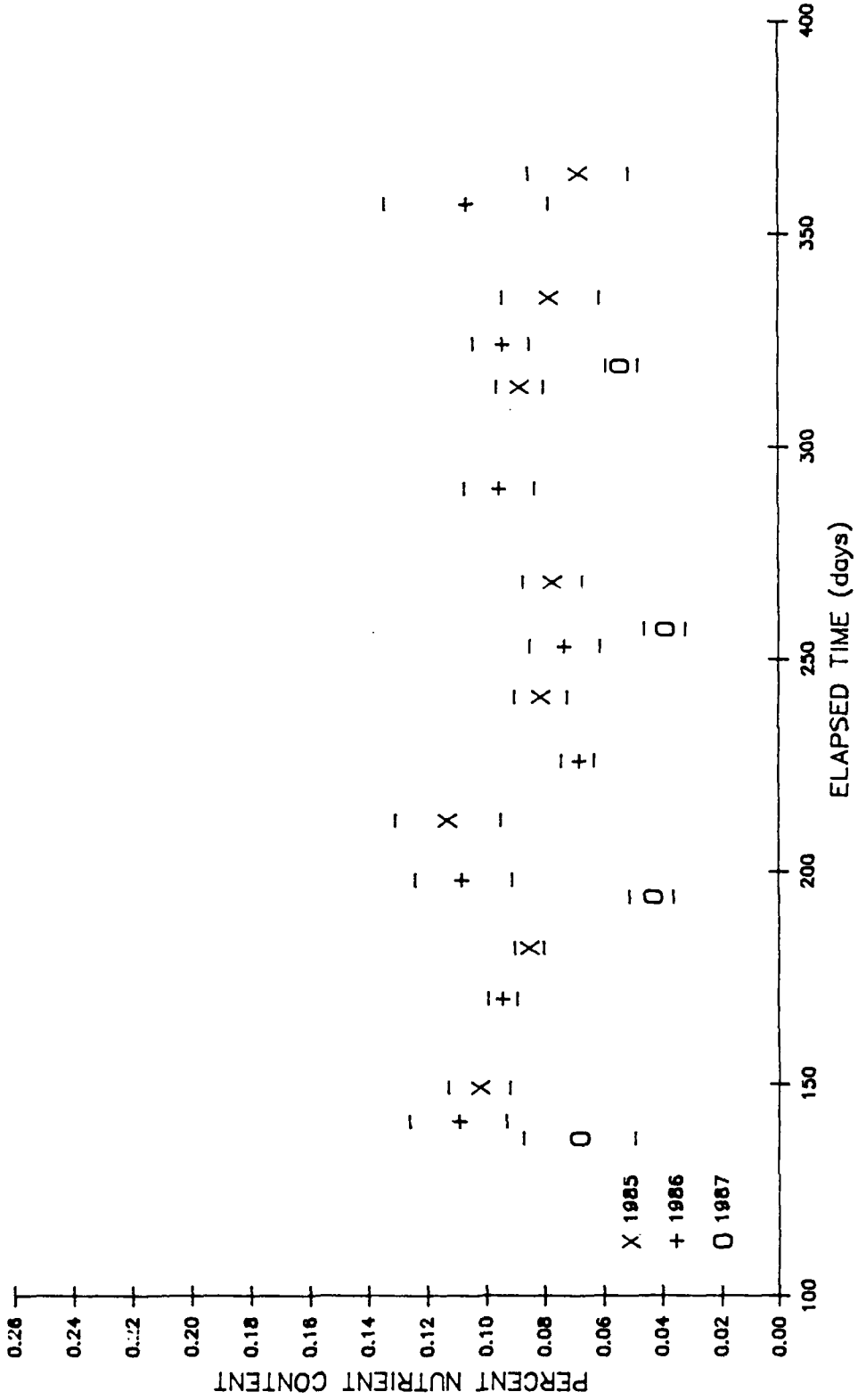

FIGURE 169. Percent potassium content of bulk maple leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

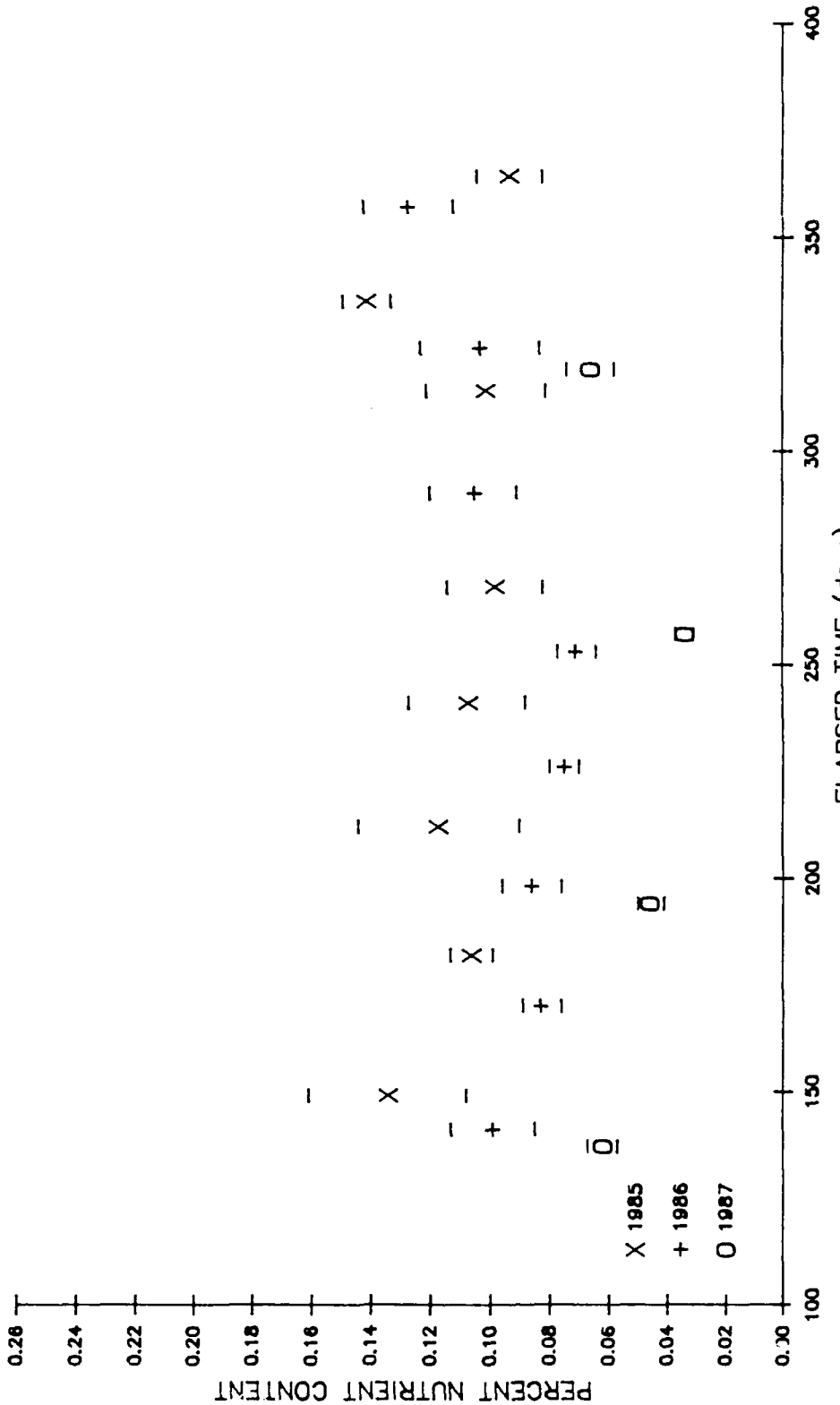

FIGURE 170. Percent potassium content of bulk maple leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

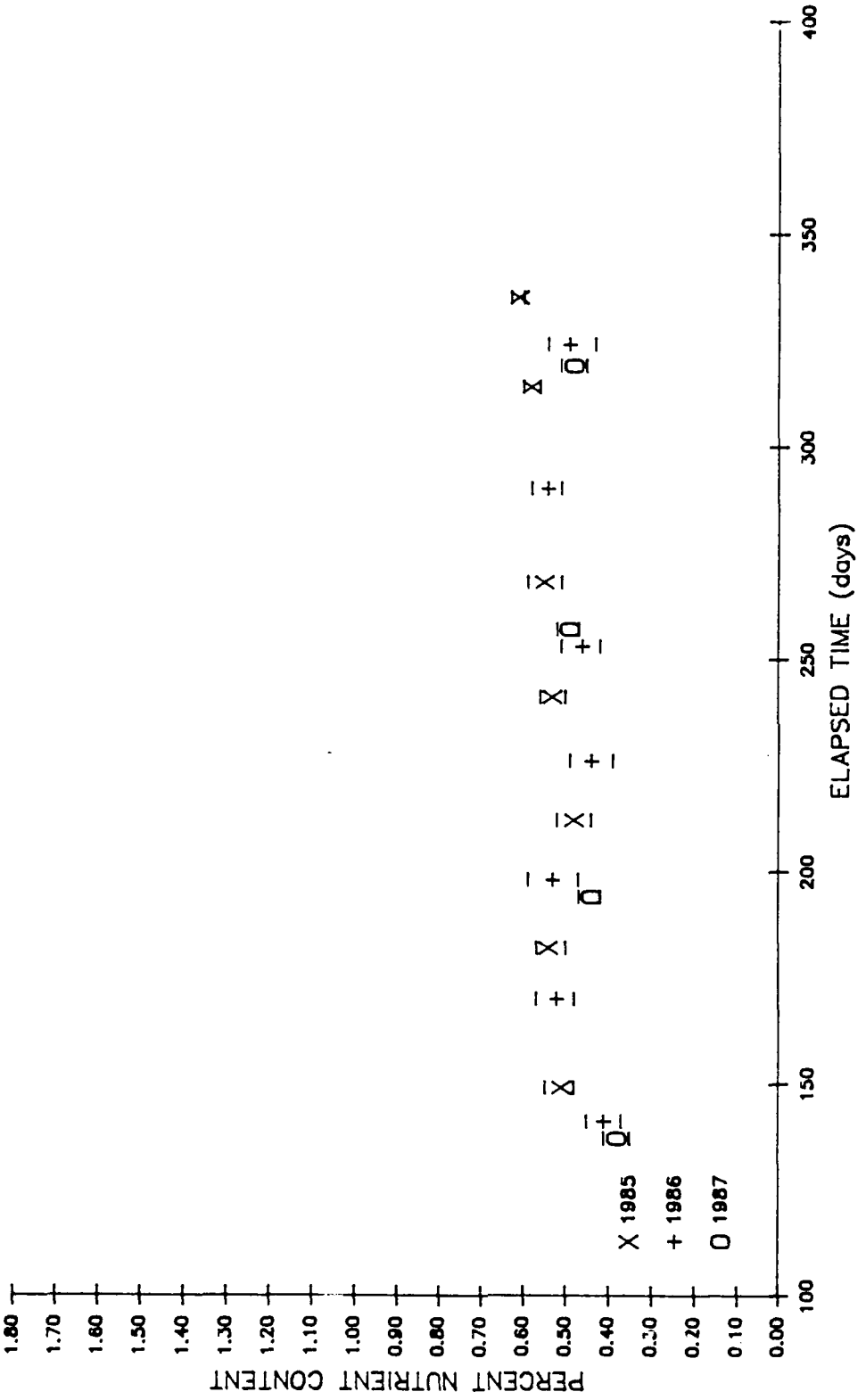

FIGURE 171. Percent calcium content of bulk pine needle samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

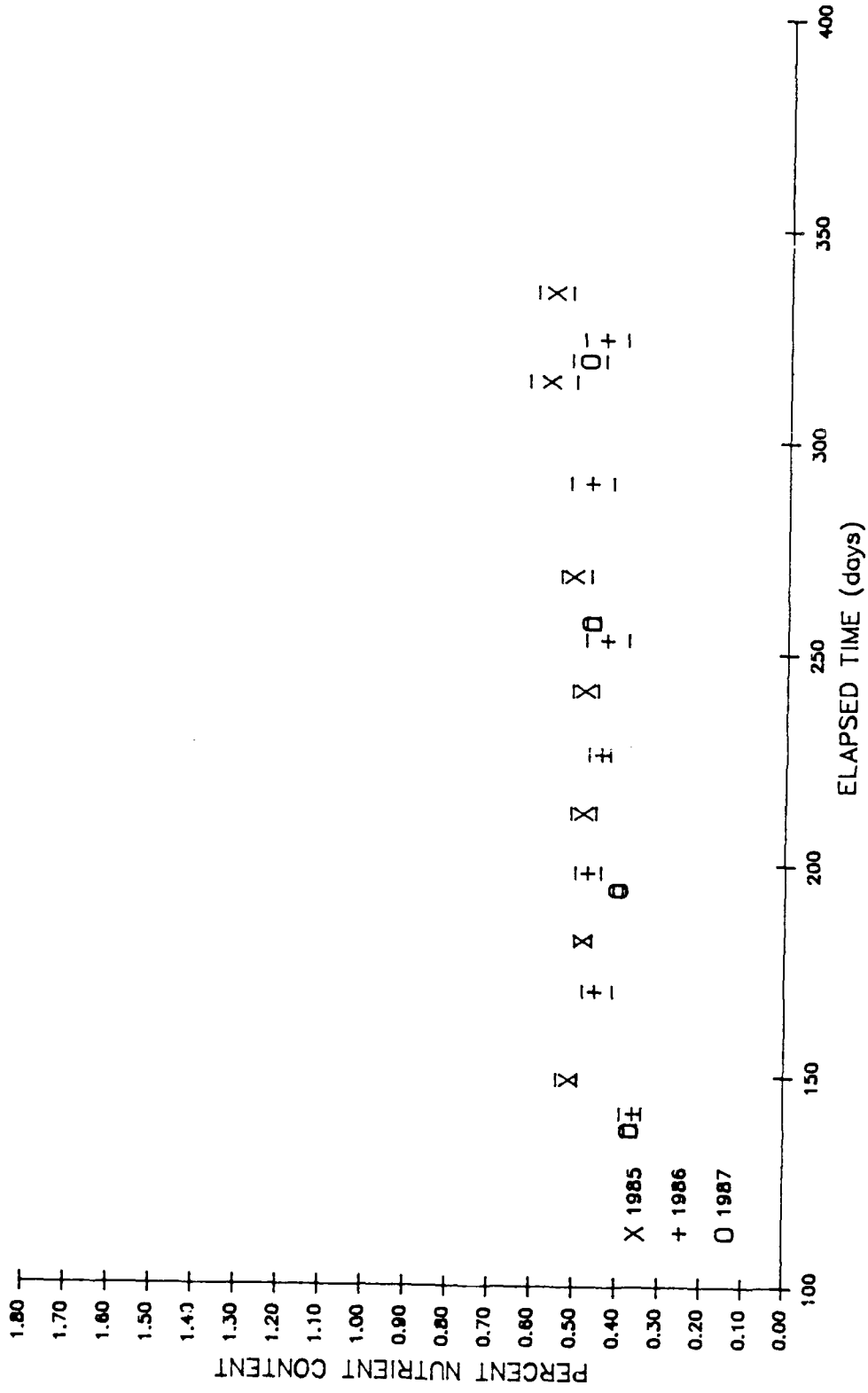

FIGURE 172. Percent calcium content of bulk pine needle samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

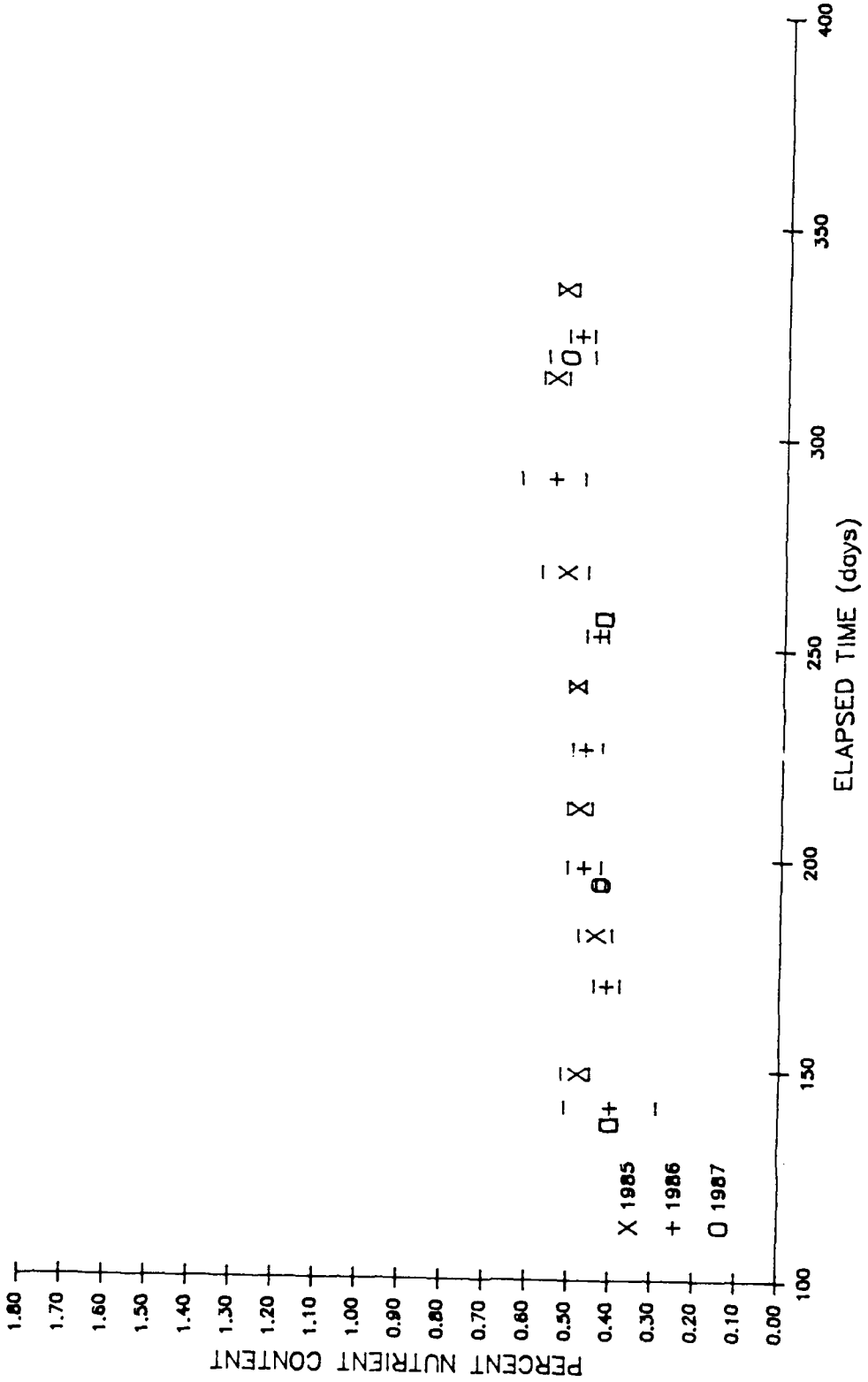

FIGURE 173. Percent calcium content of bulk pine needle samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

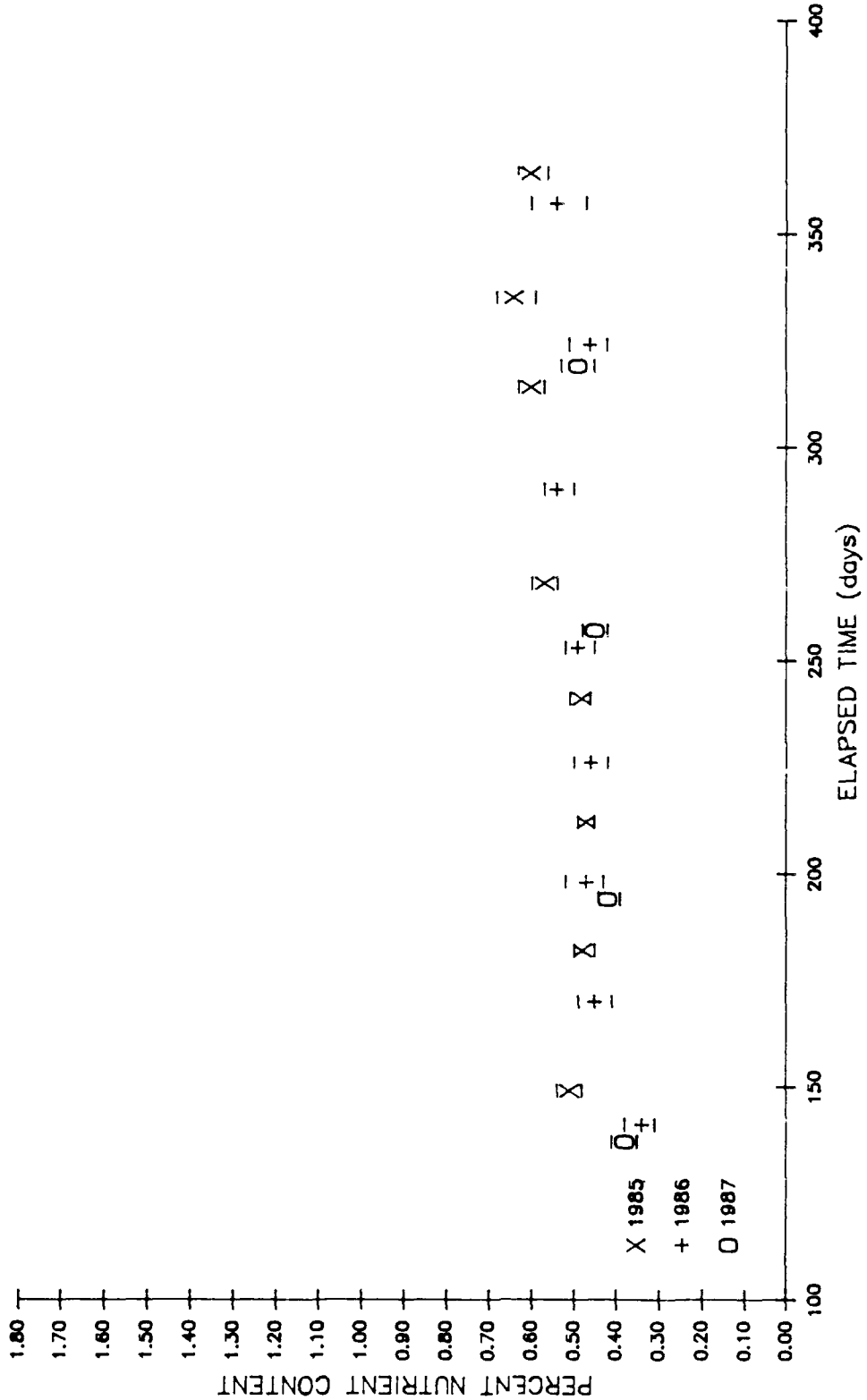

FIGURE 174. Percent calcium content of bulk pine needle samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

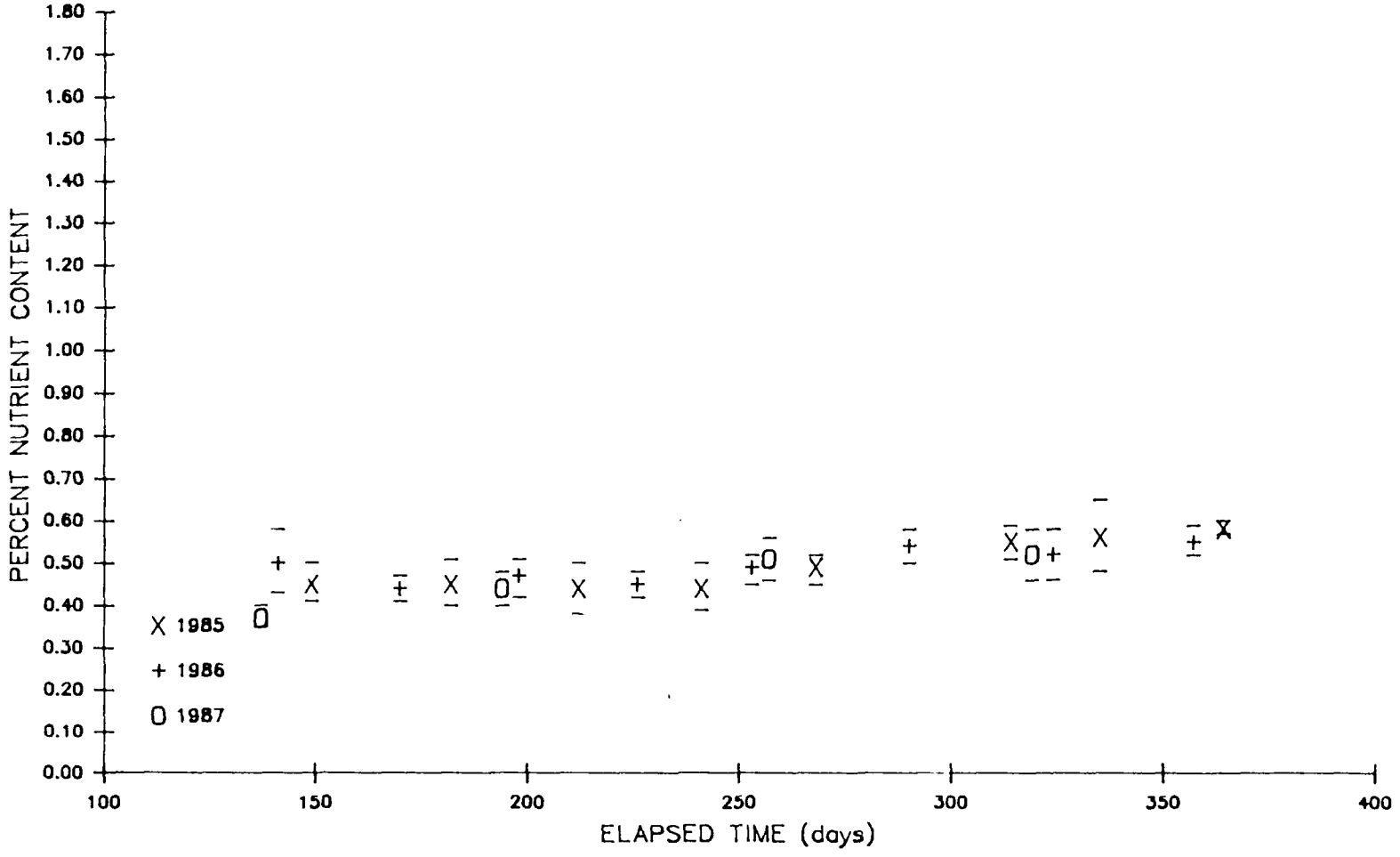

FIGURE 175. Percent calcium content of bulk pine needle samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

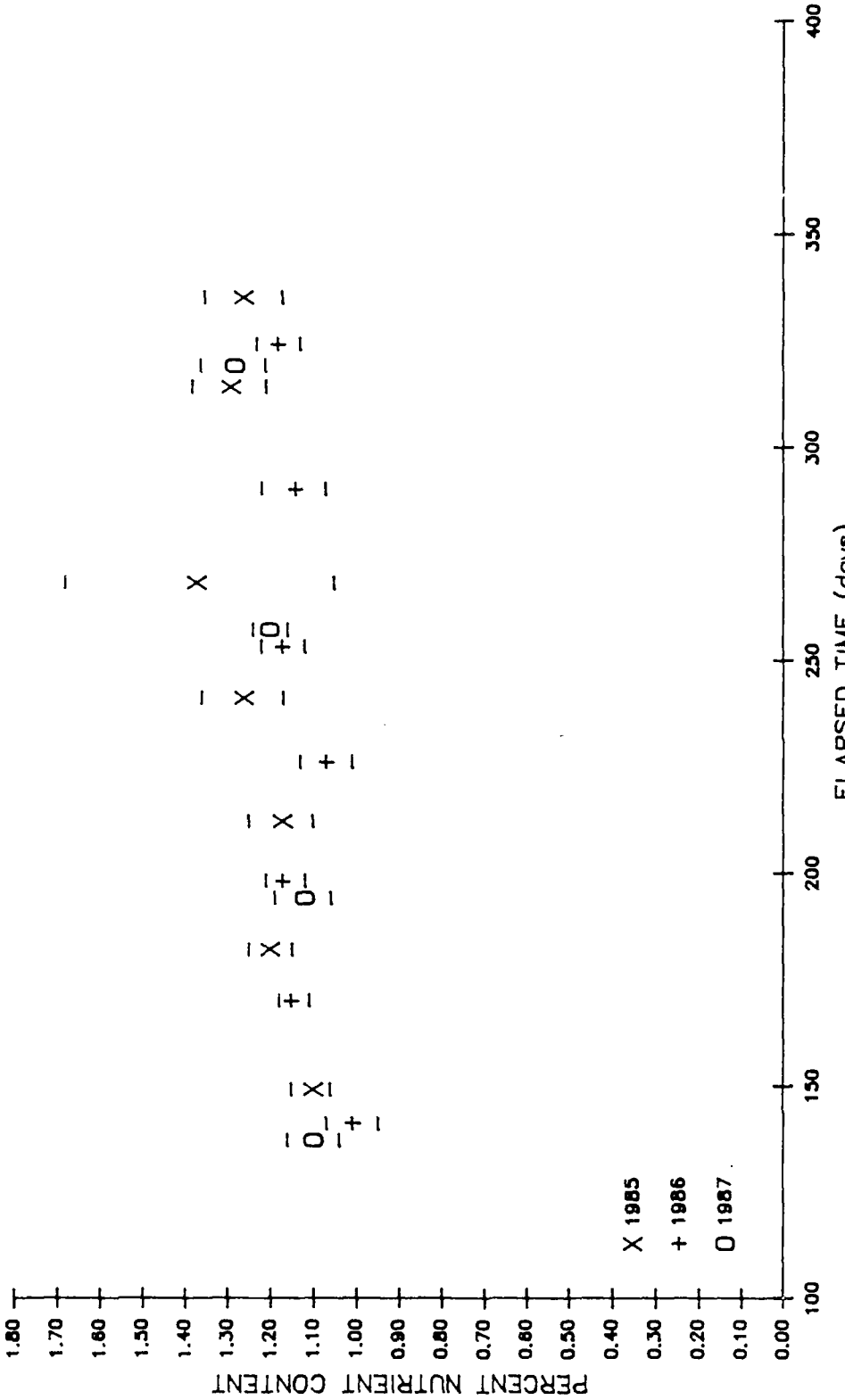

FIGURE 176. Percent calcium content of bulk oak leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

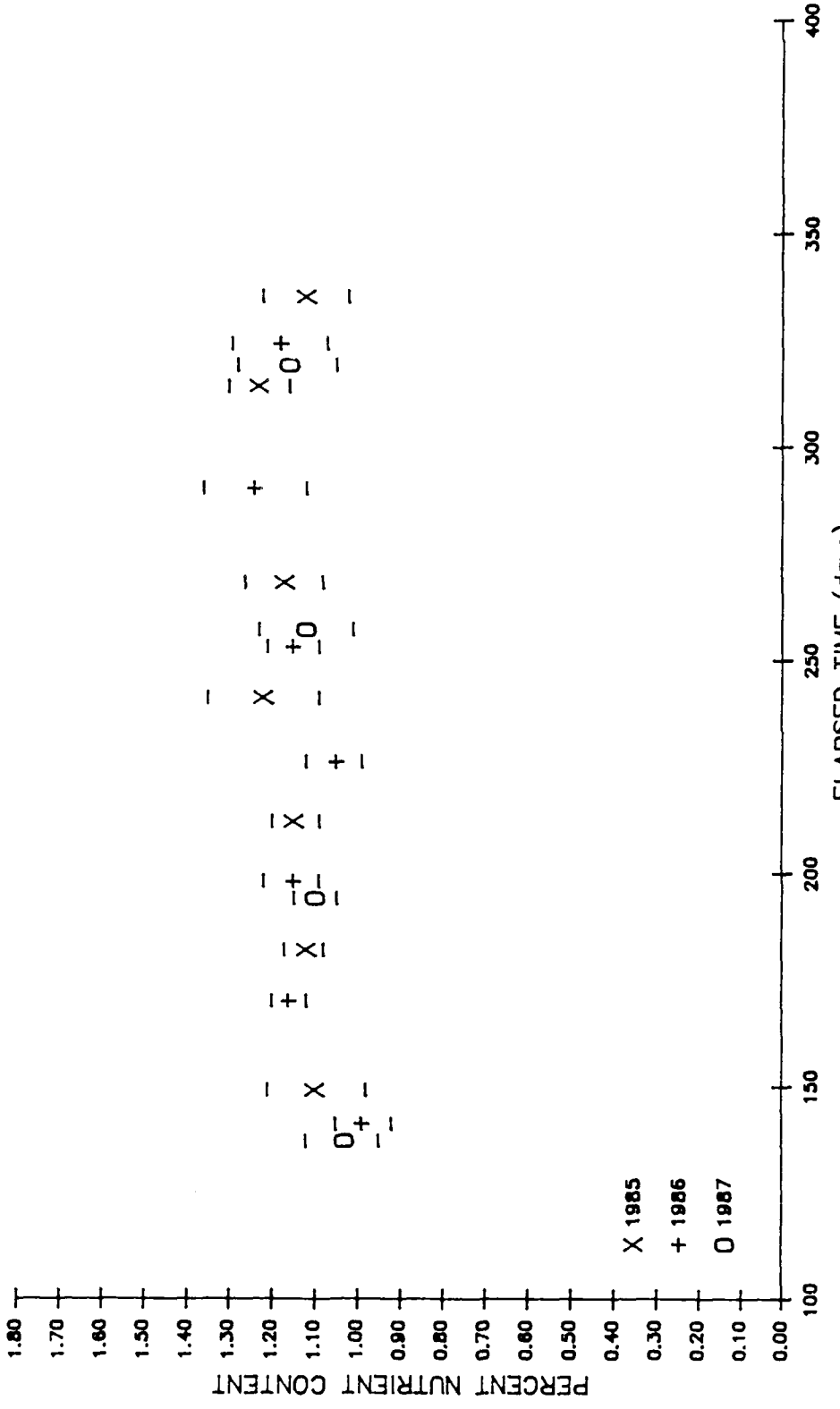

FIGURE 177. Percent calcium content of bulk oak leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

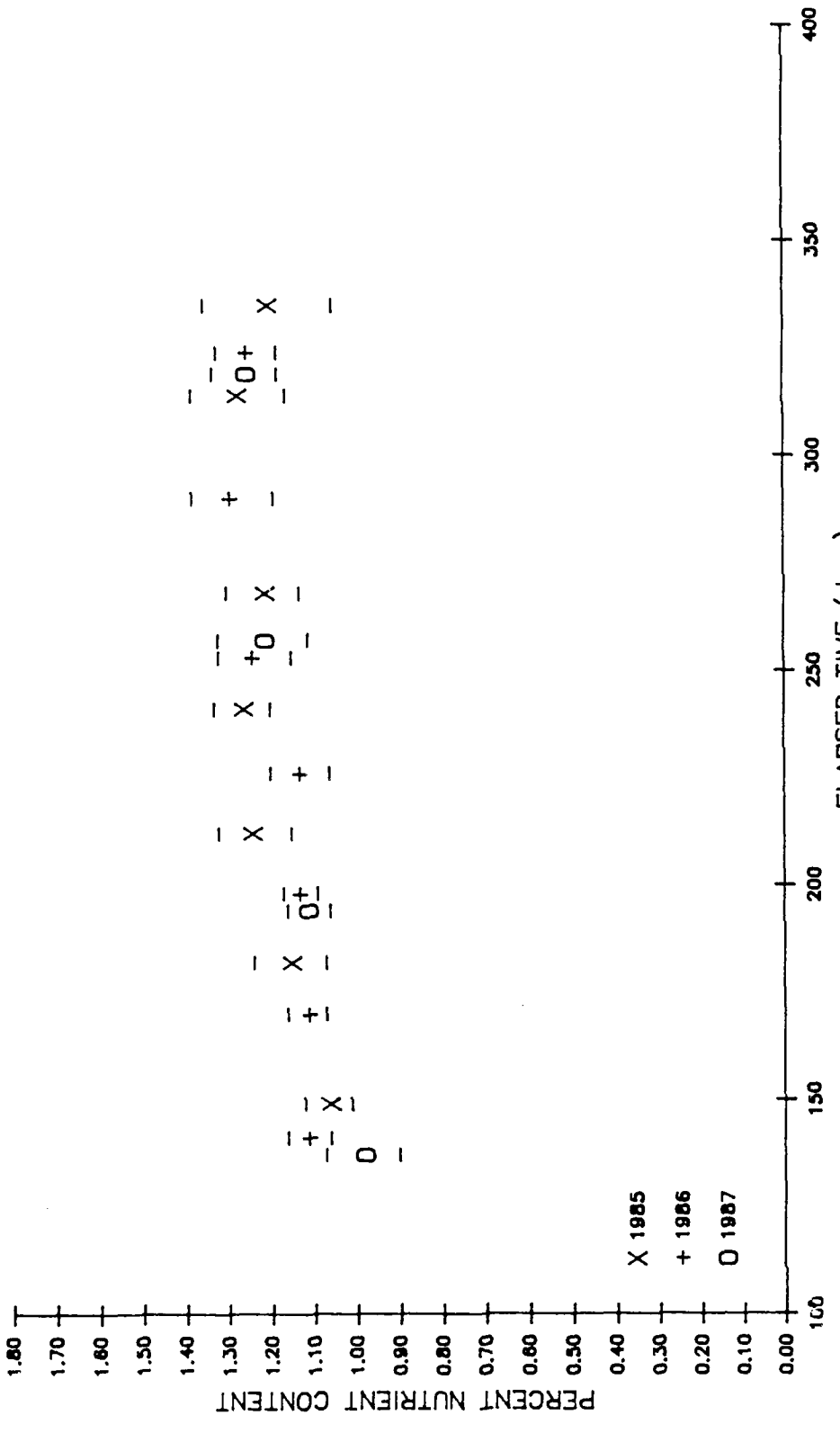

FIGURE 178. Percent calcium content of bulk oak leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

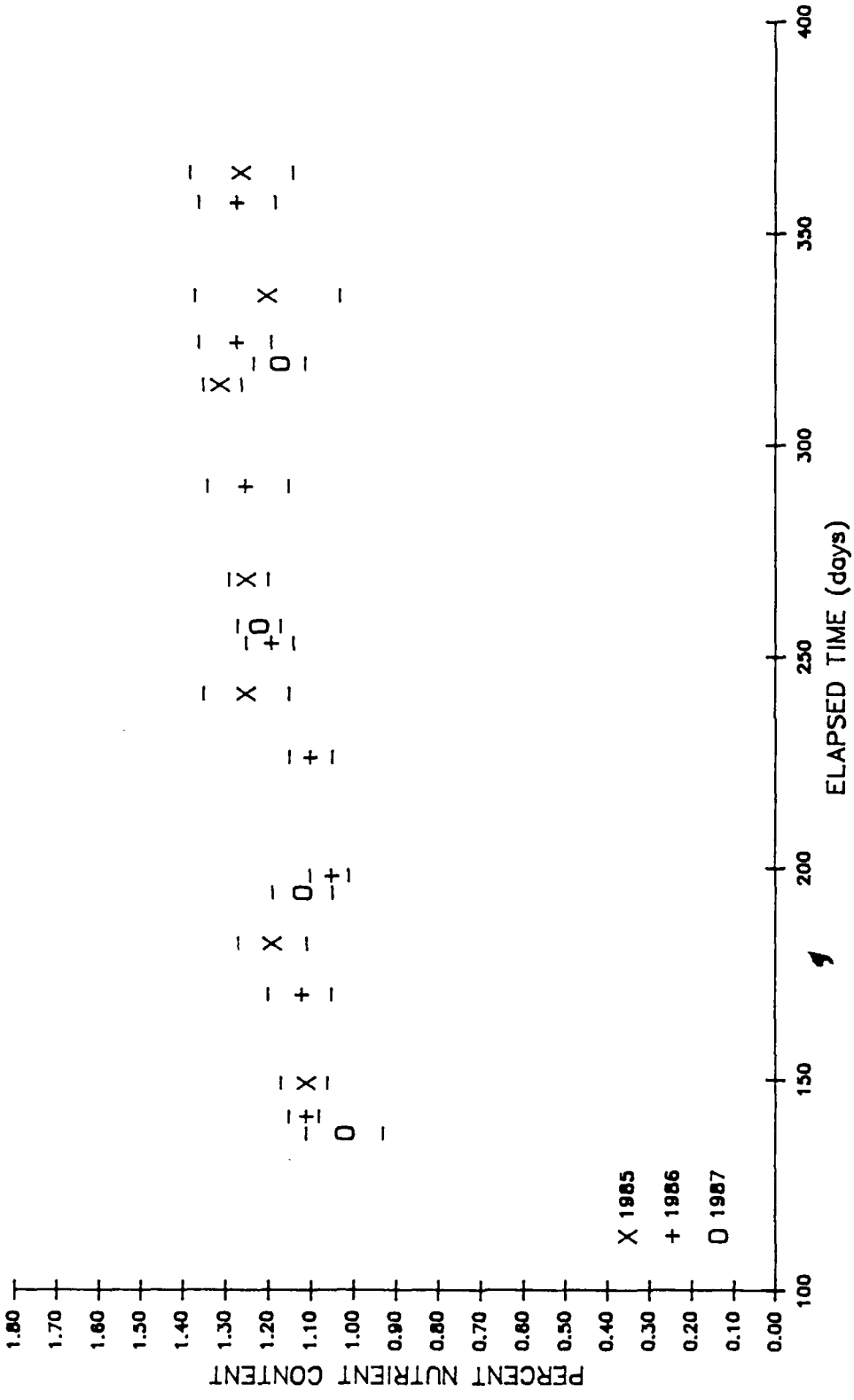

FIGURE 179. Percent calcium content of bulk oak leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

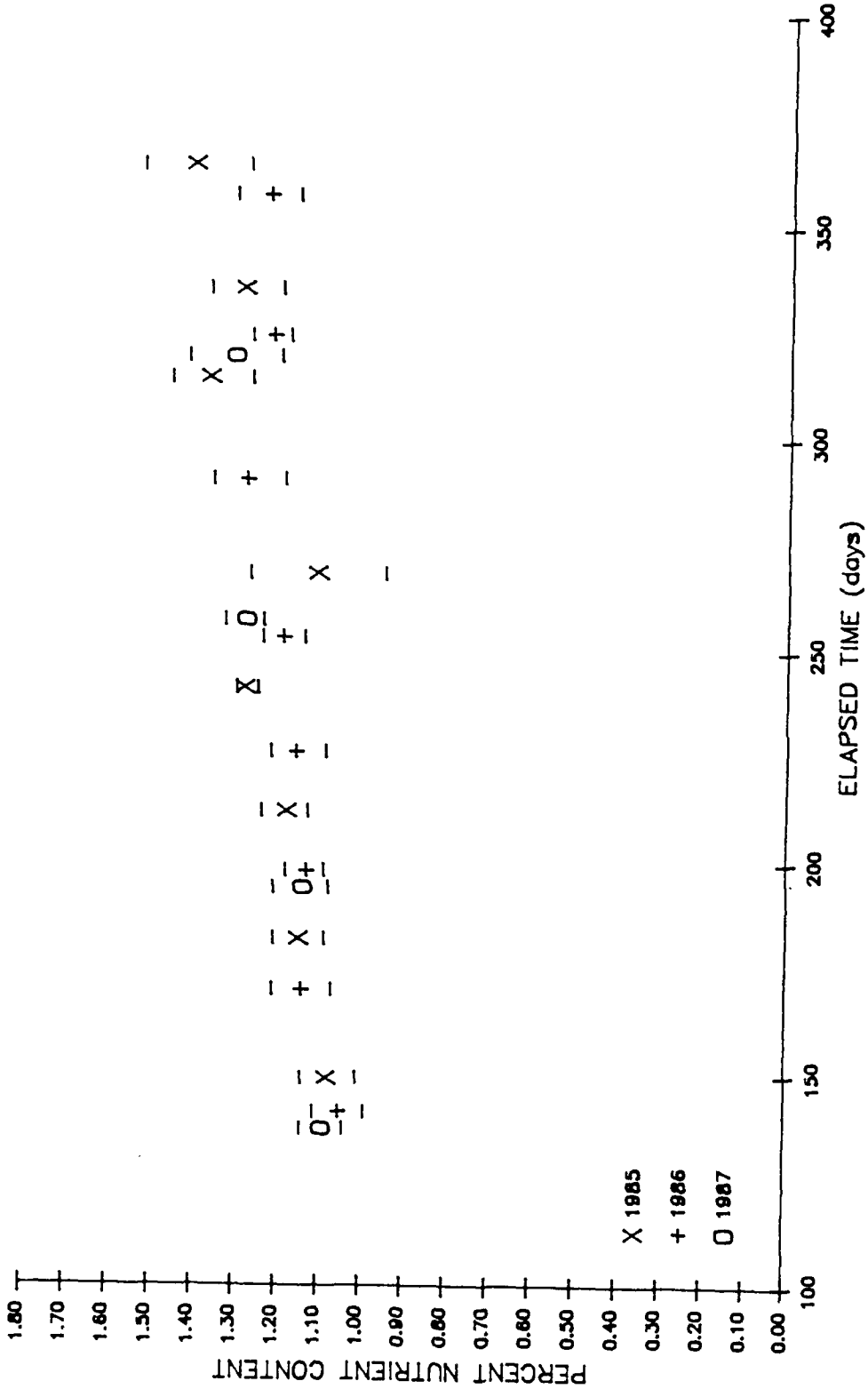

FIGURE 180. Percent calcium content of bulk oak leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

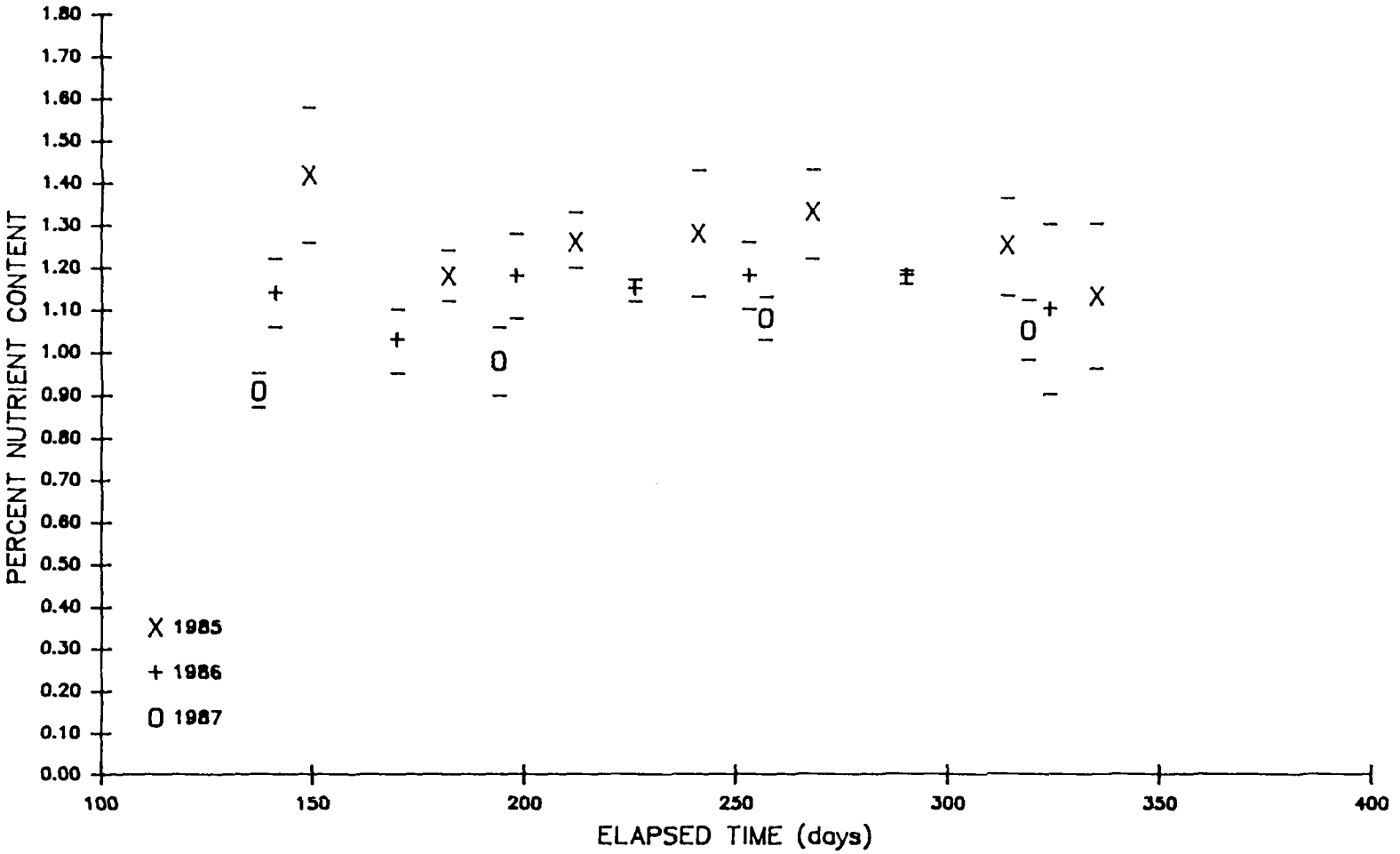

FIGURE 181. Percent calcium content of bulk maple leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

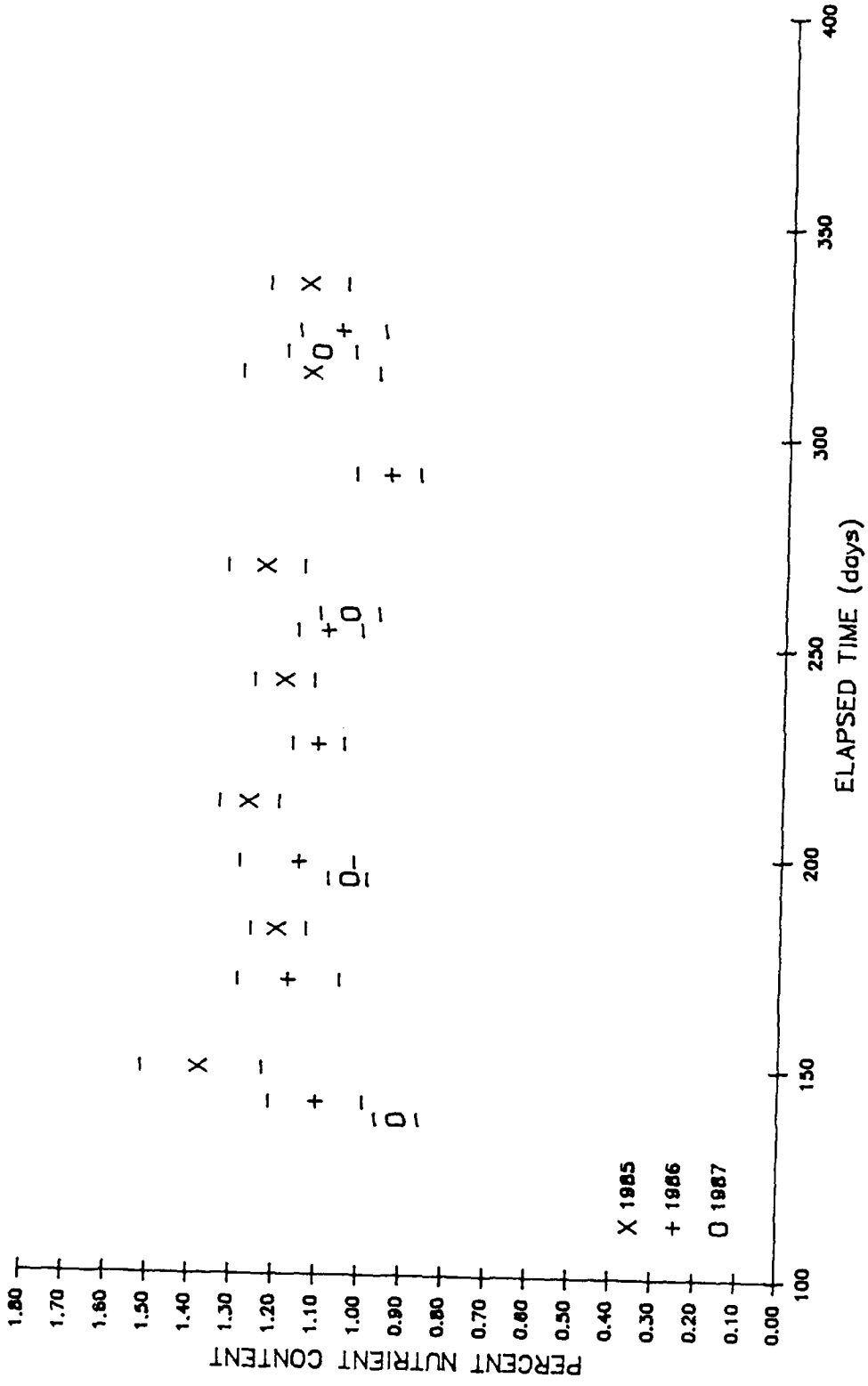

FIGURE 182. Percent calcium content of bulk maple leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

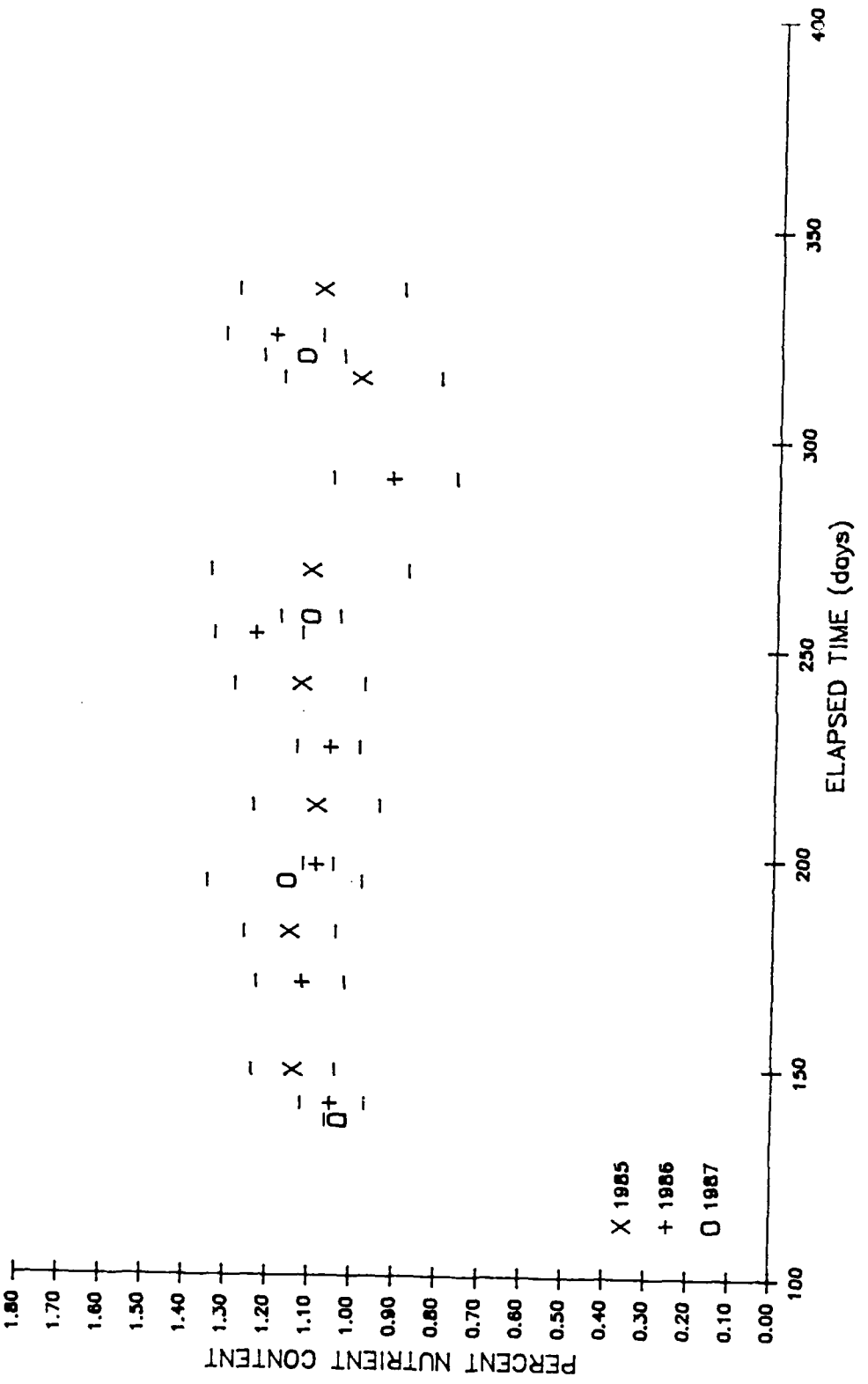

FIGURE 183. Percent calcium content of bulk maple leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

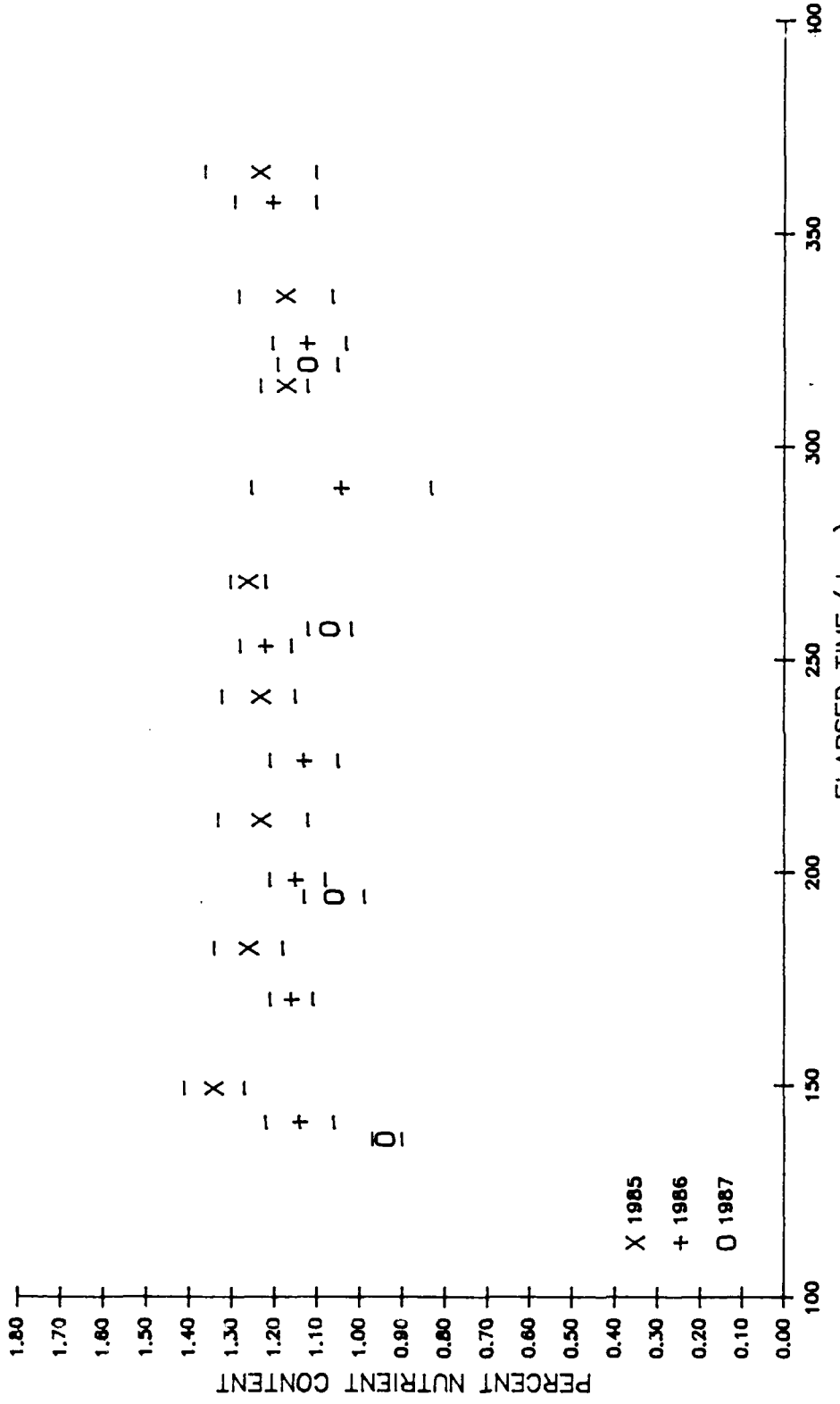

FIGURE 184. Percent calcium content of bulk maple leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

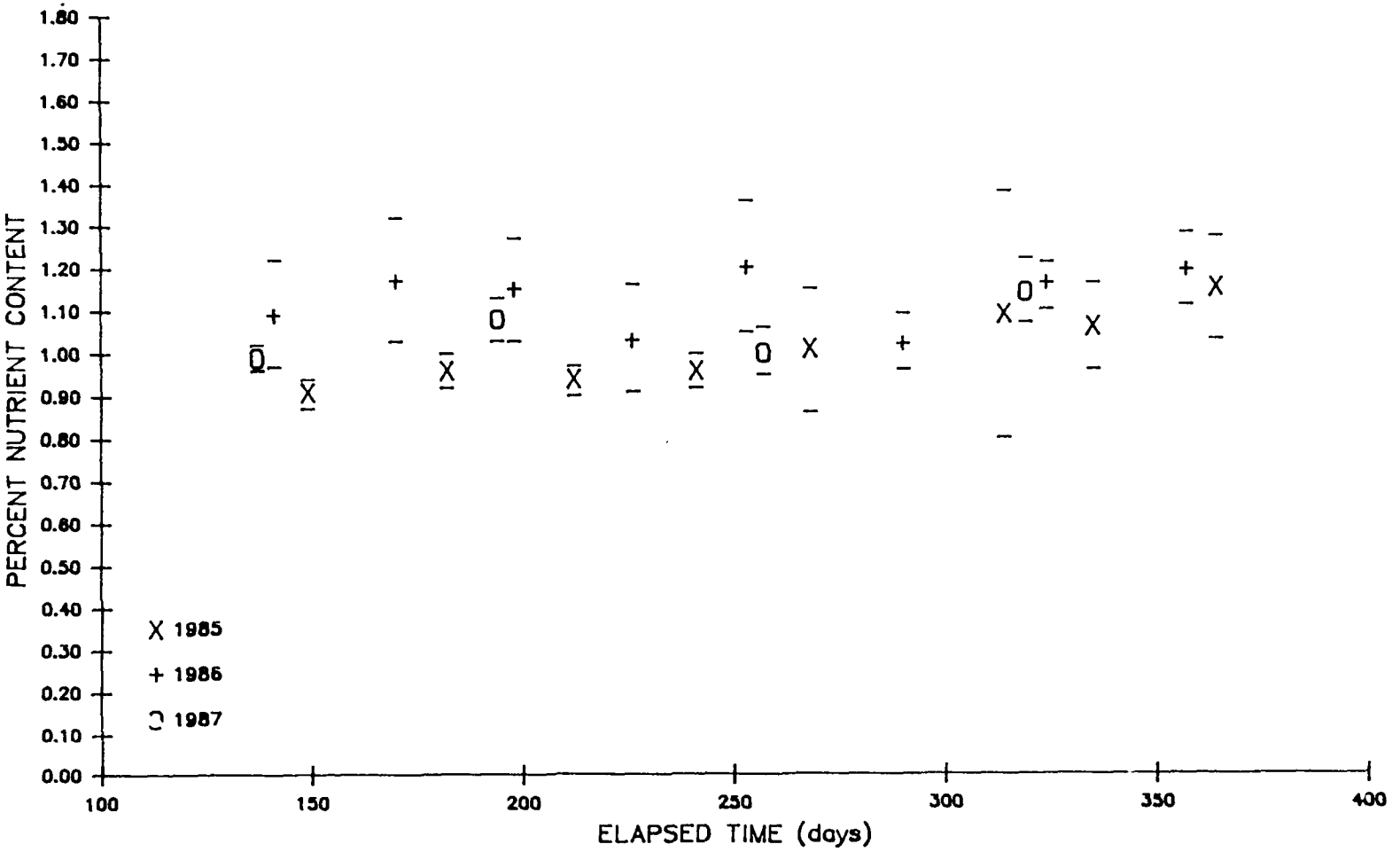

FIGURE 185. Percent calcium content of bulk maple leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

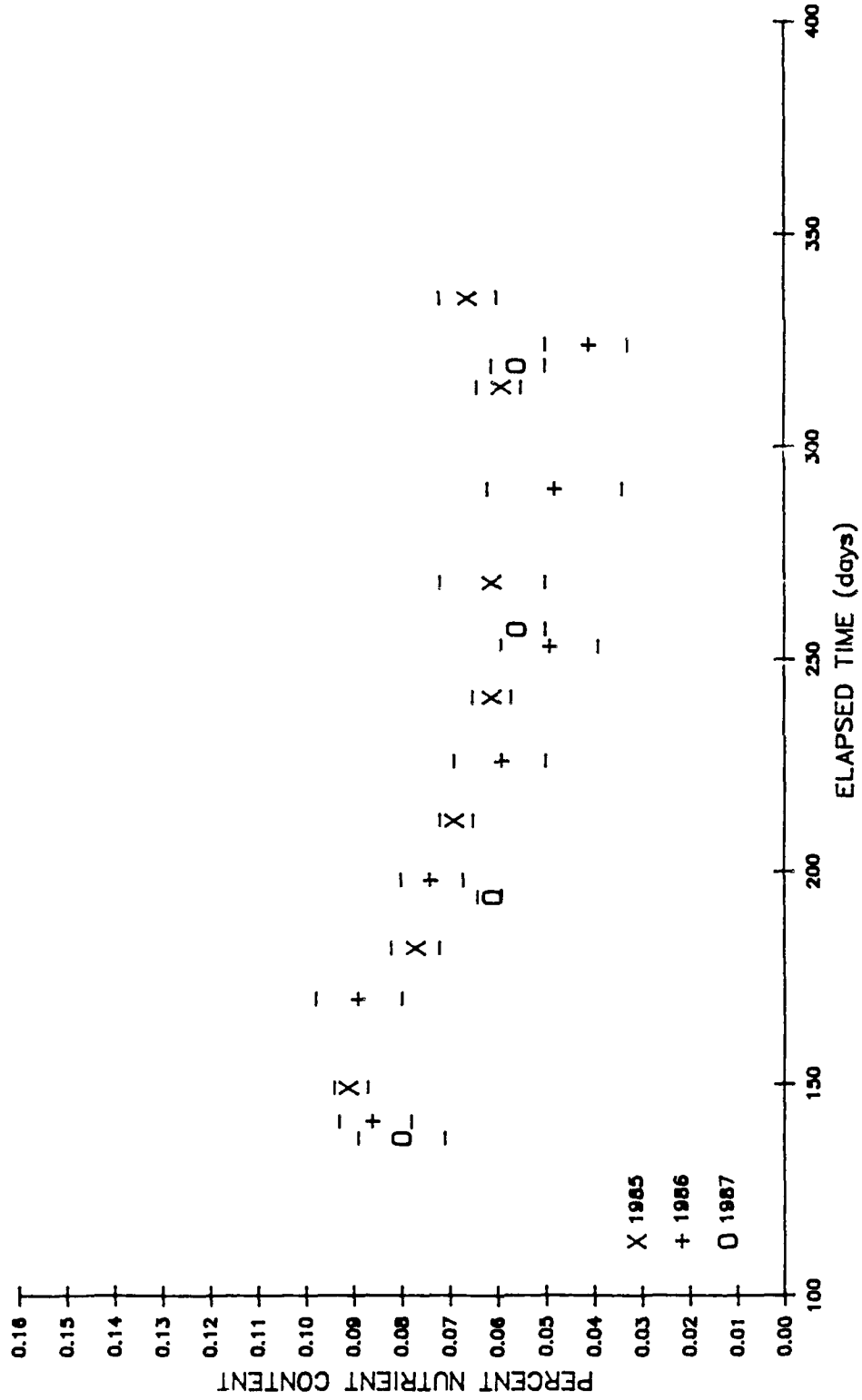

FIGURE 186. Percent magnesium content of bulk pine needle samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

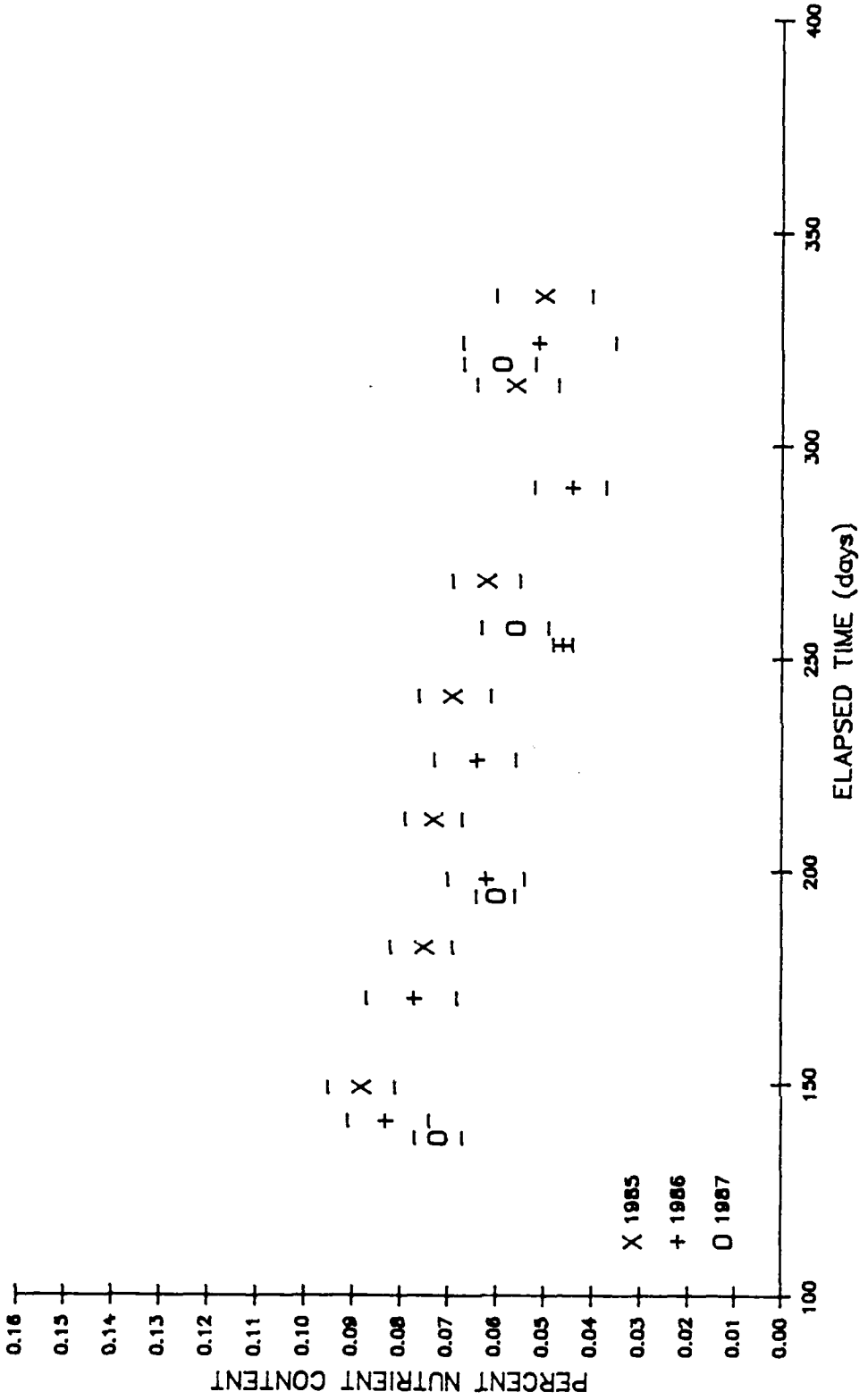

FIGURE 187. Percent magnesium content of bulk pine needle samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

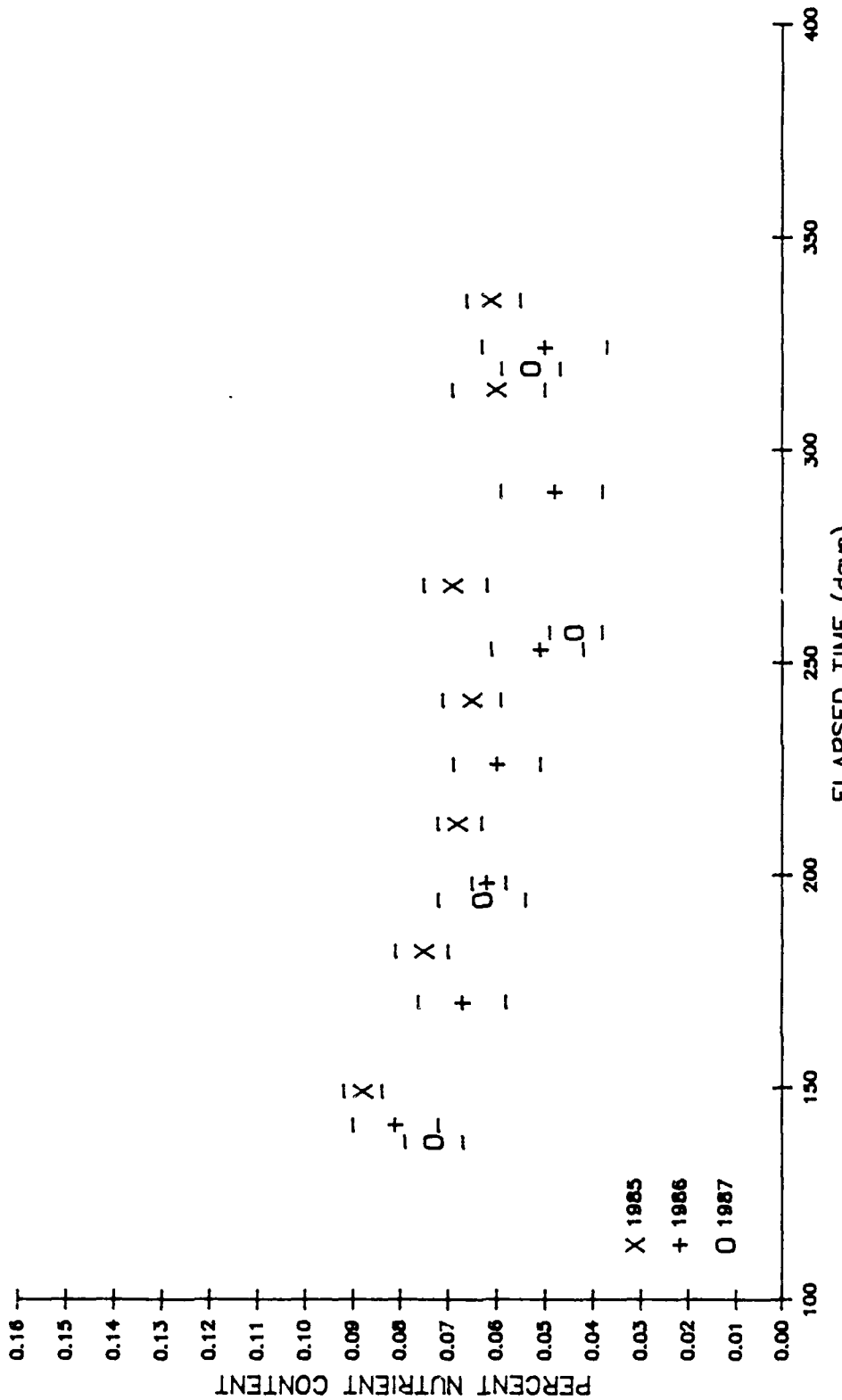

FIGURE 188. Percent magnesium content of bulk pine needle samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

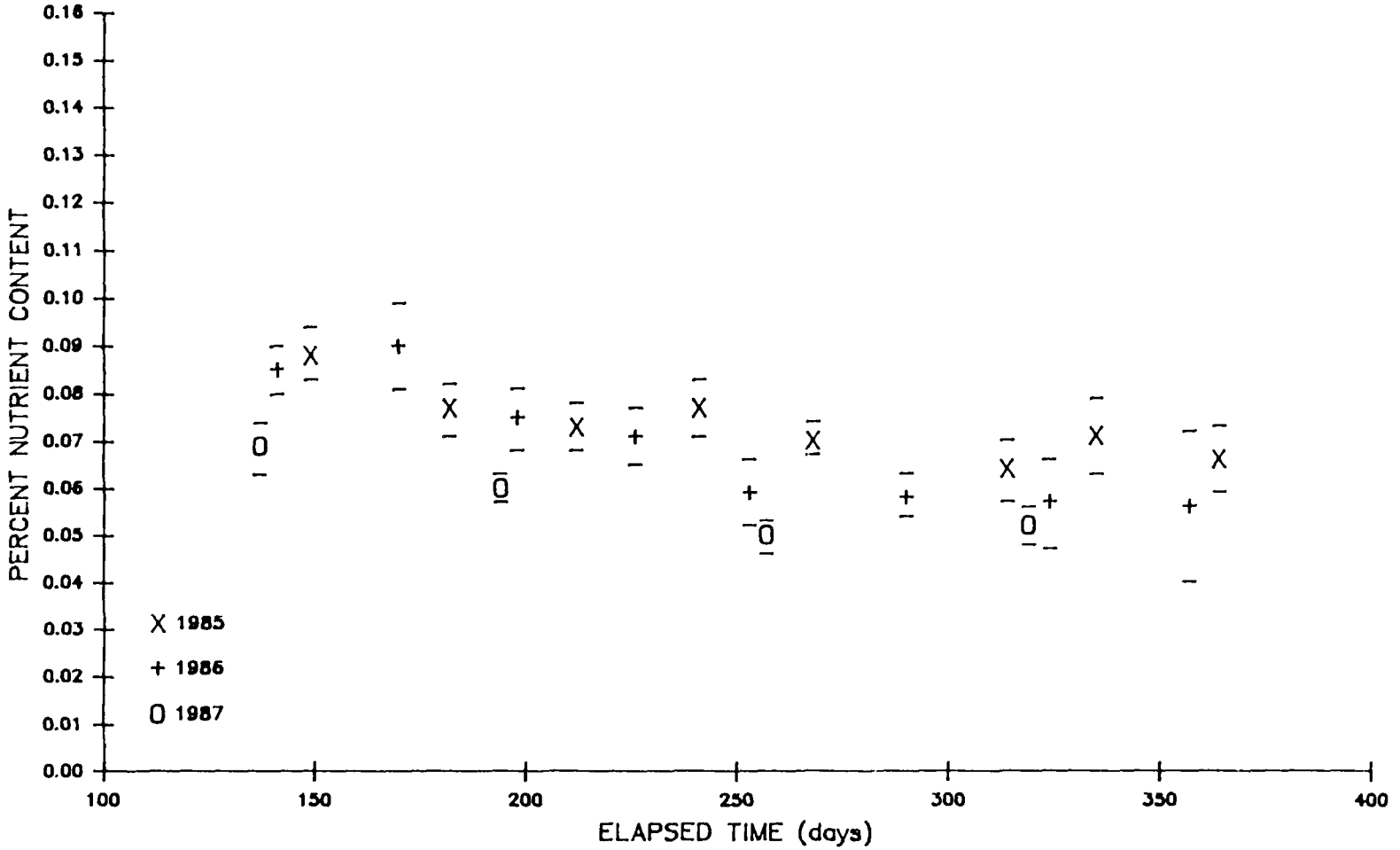

FIGURE 189. Percent magnesium content of bulk pine needle samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

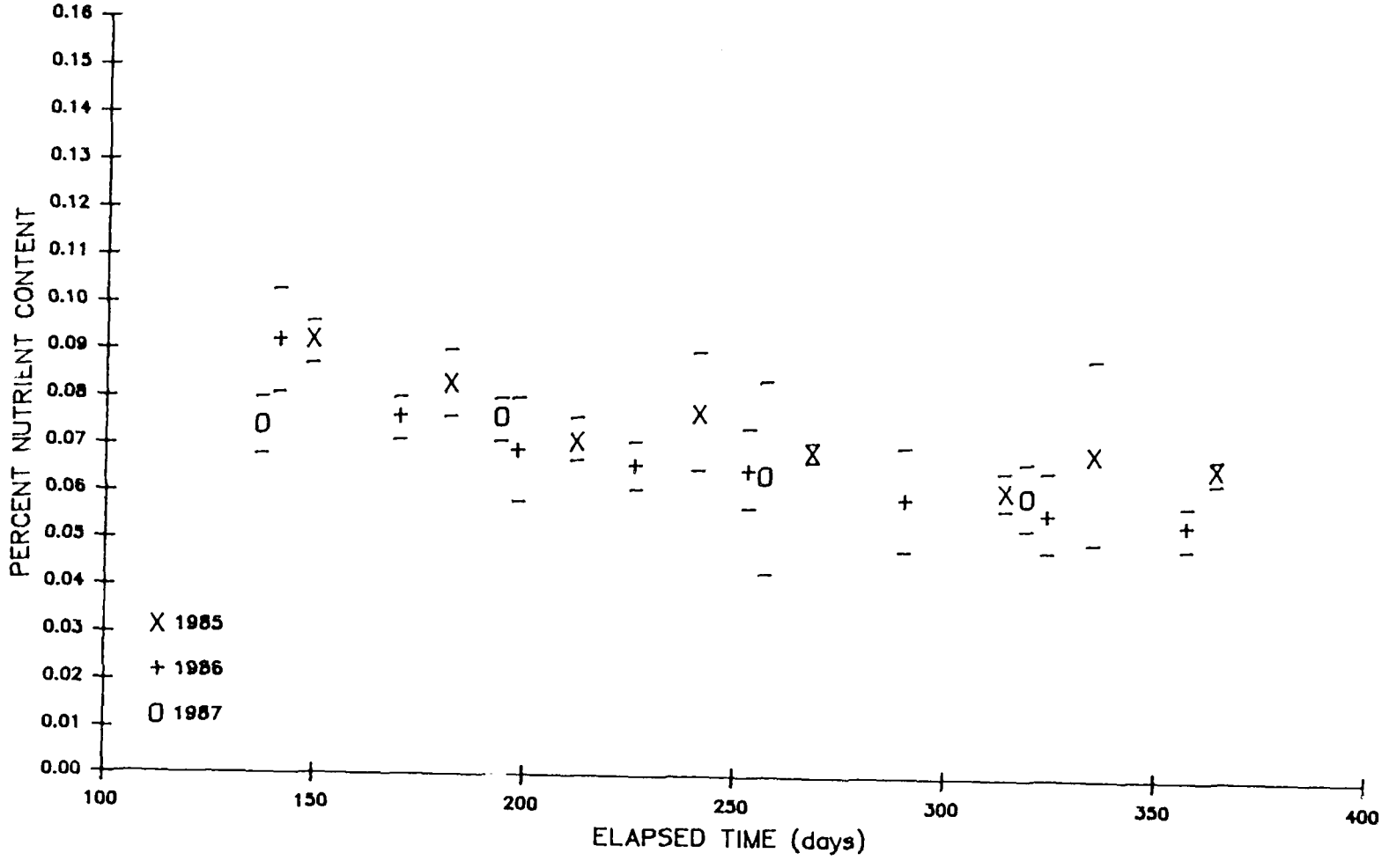

FIGURE 190. Percent magnesium content of bulk pine needle samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

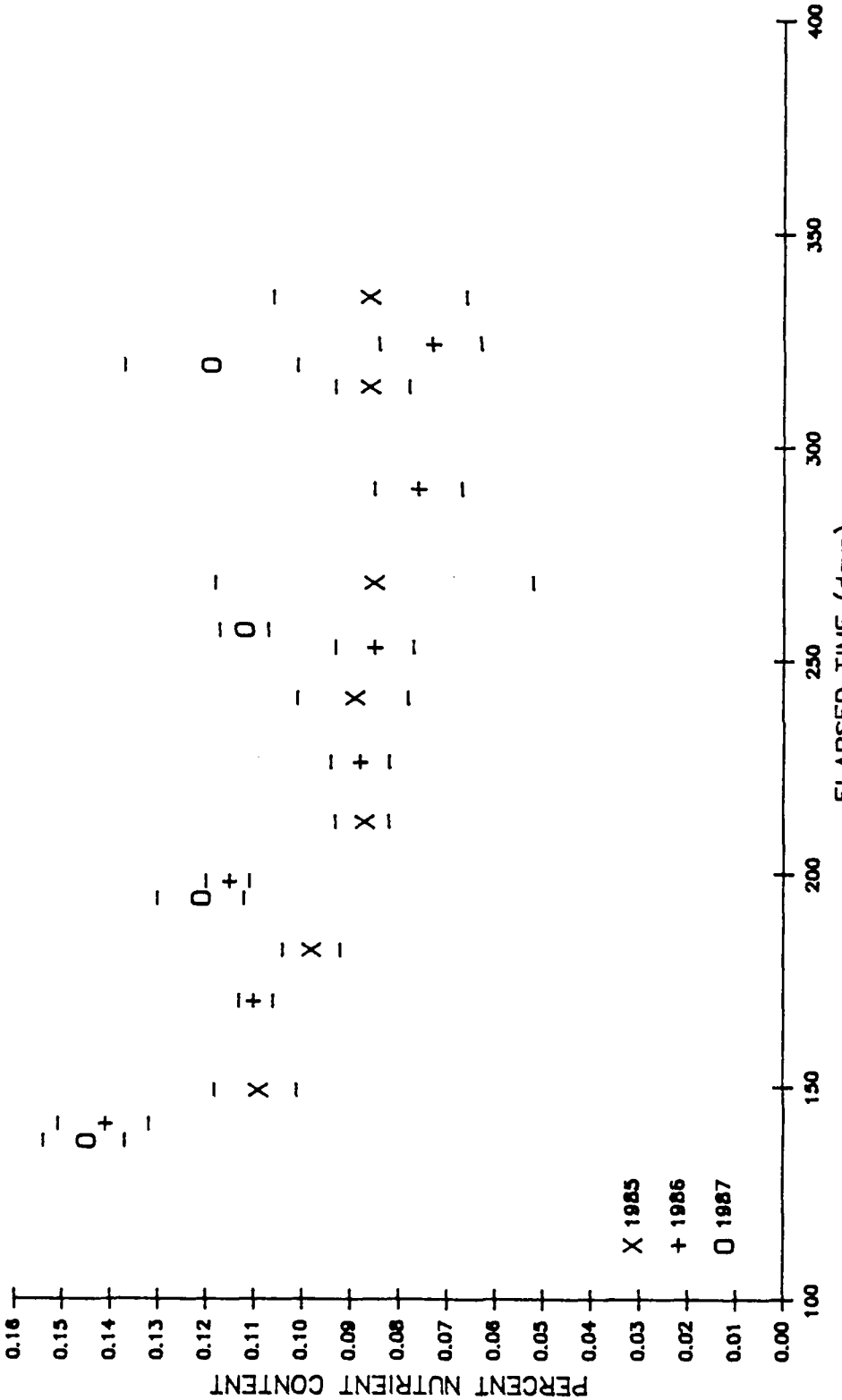

FIGURE 191. Percent magnesium content of bulk oak leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

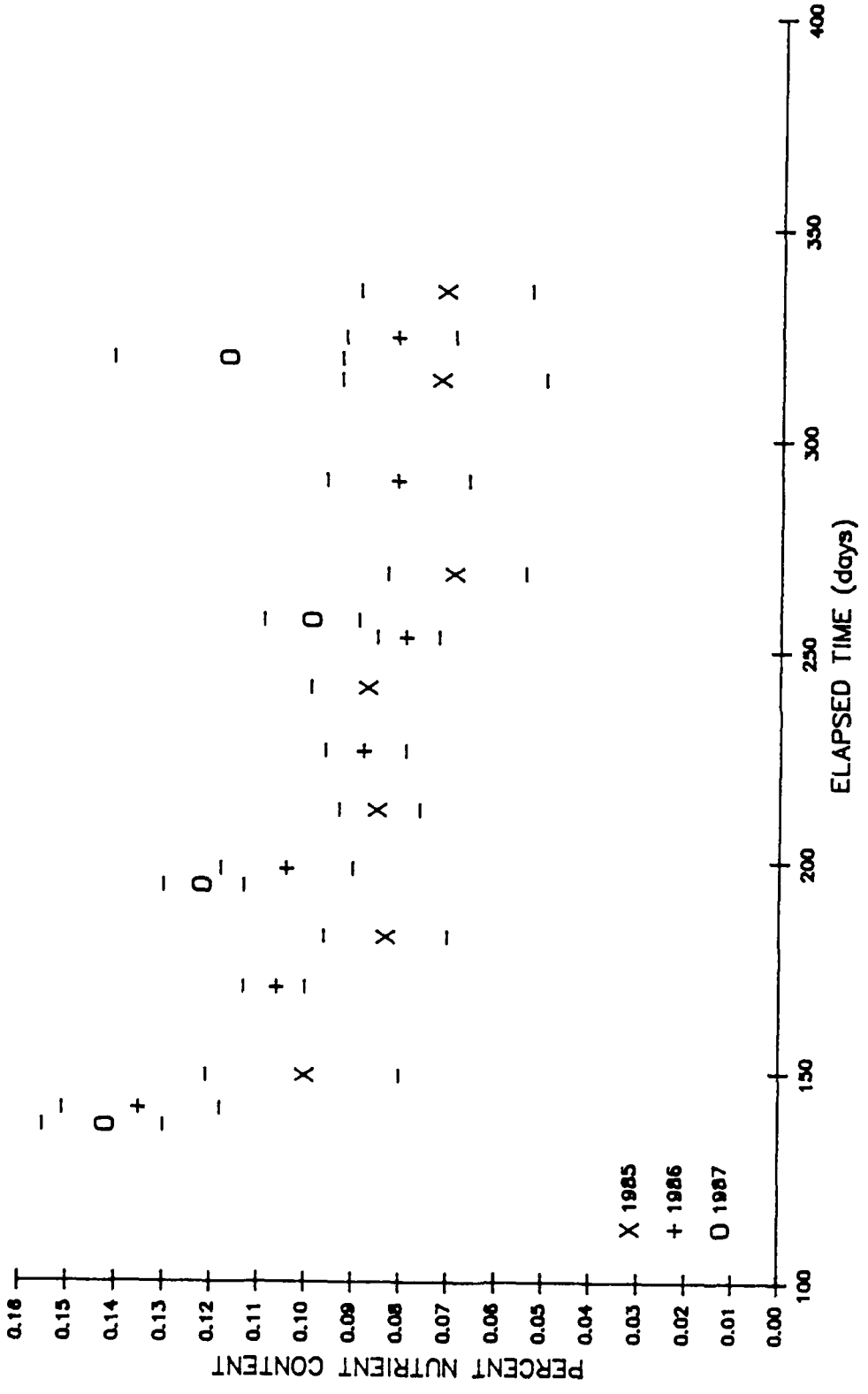

FIGURE 192. Percent magnesium content of bulk oak leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

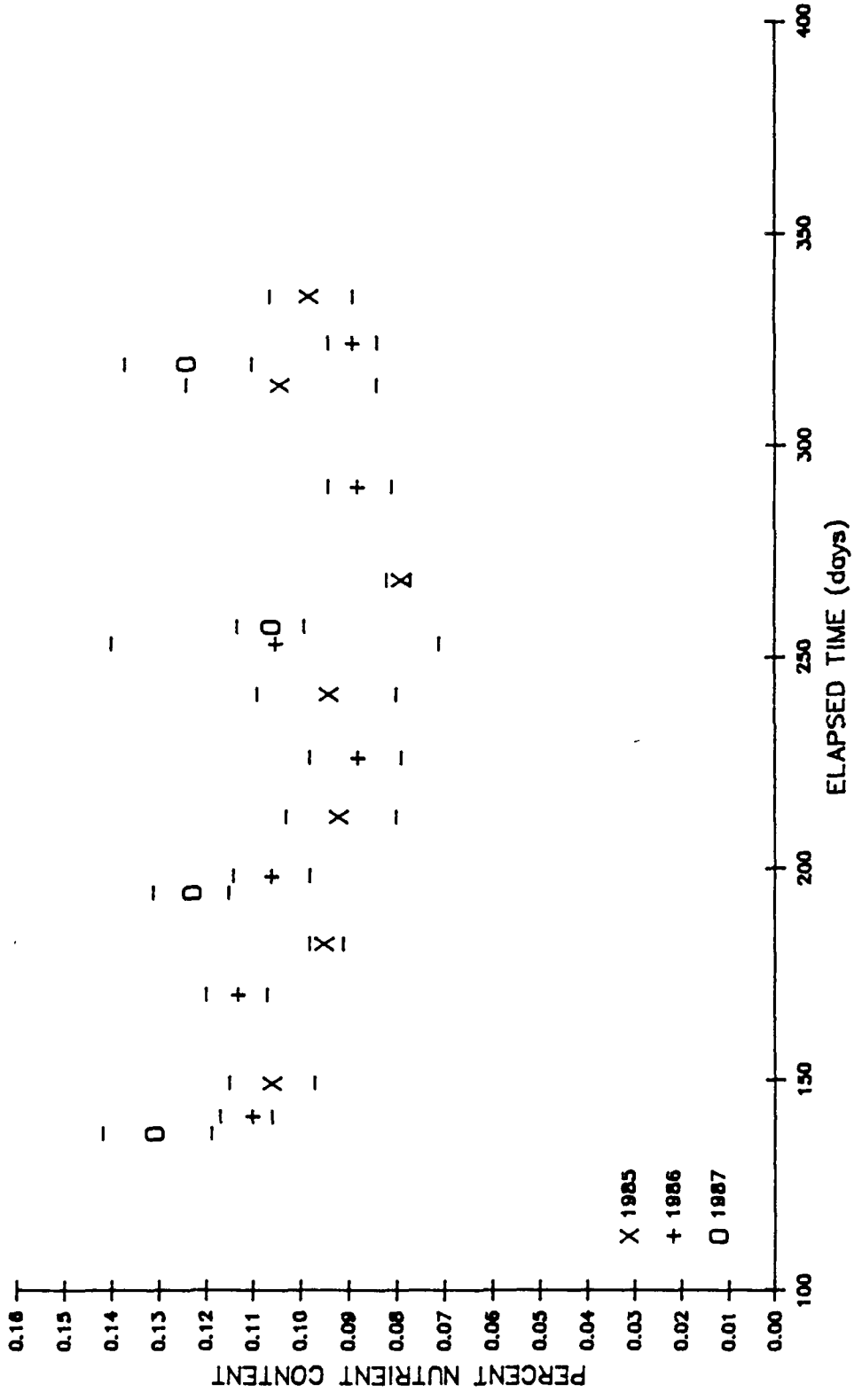

FIGURE 193. Percent magnesium content of bulk oak leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

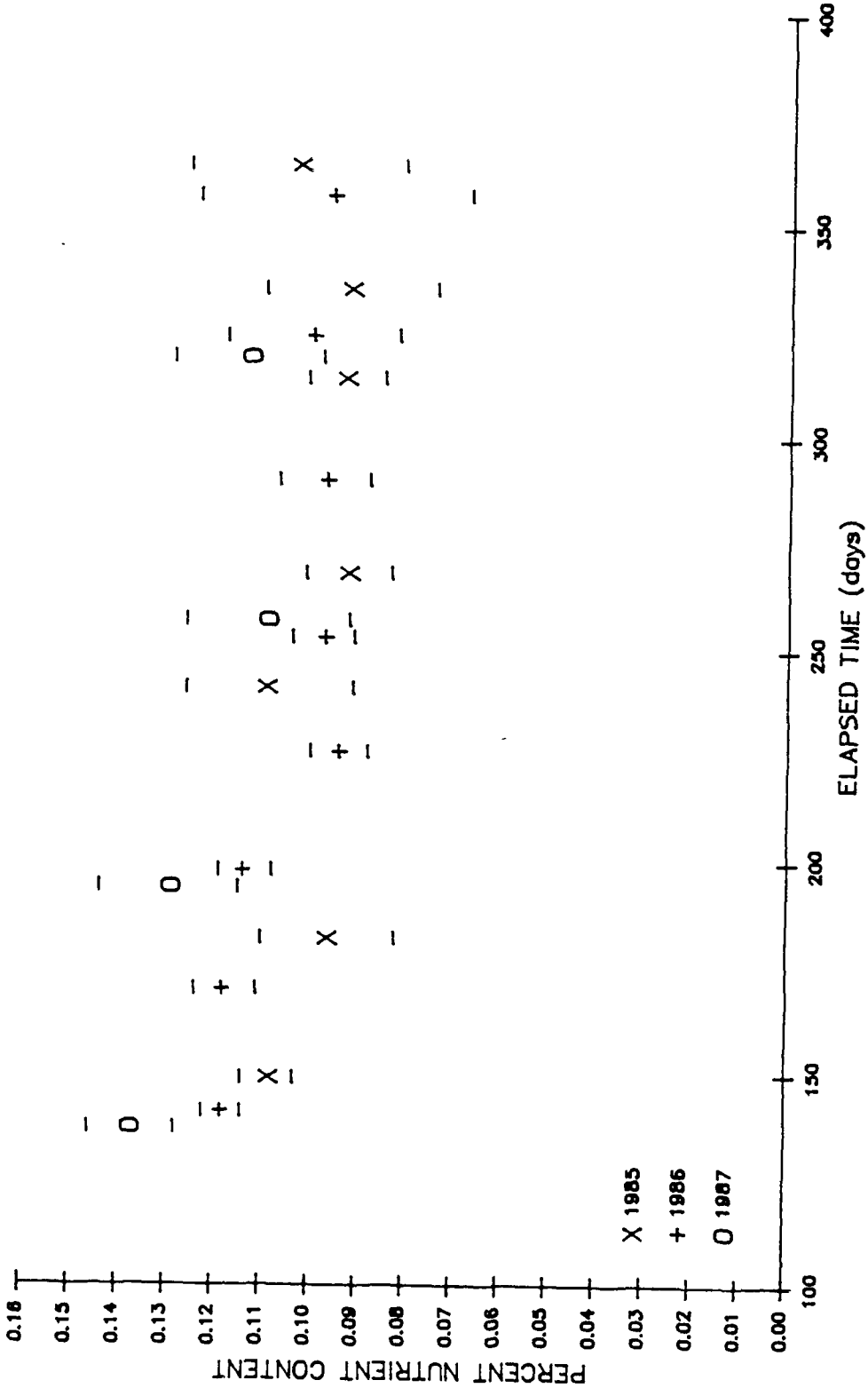

FIGURE 194. Percent magnesium content of bulk oak leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

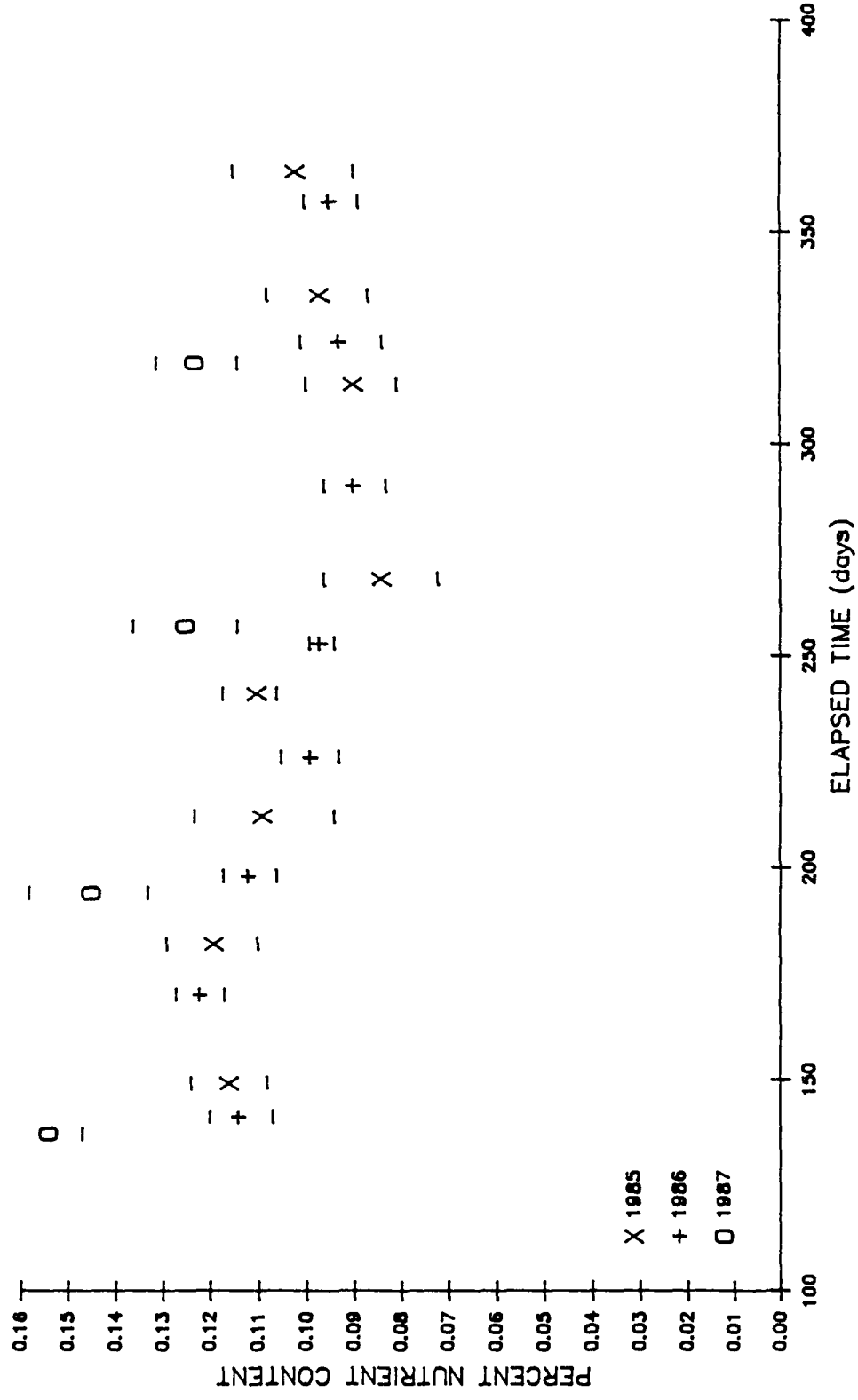

FIGURE 195. Percent magnesium content of bulk oak leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

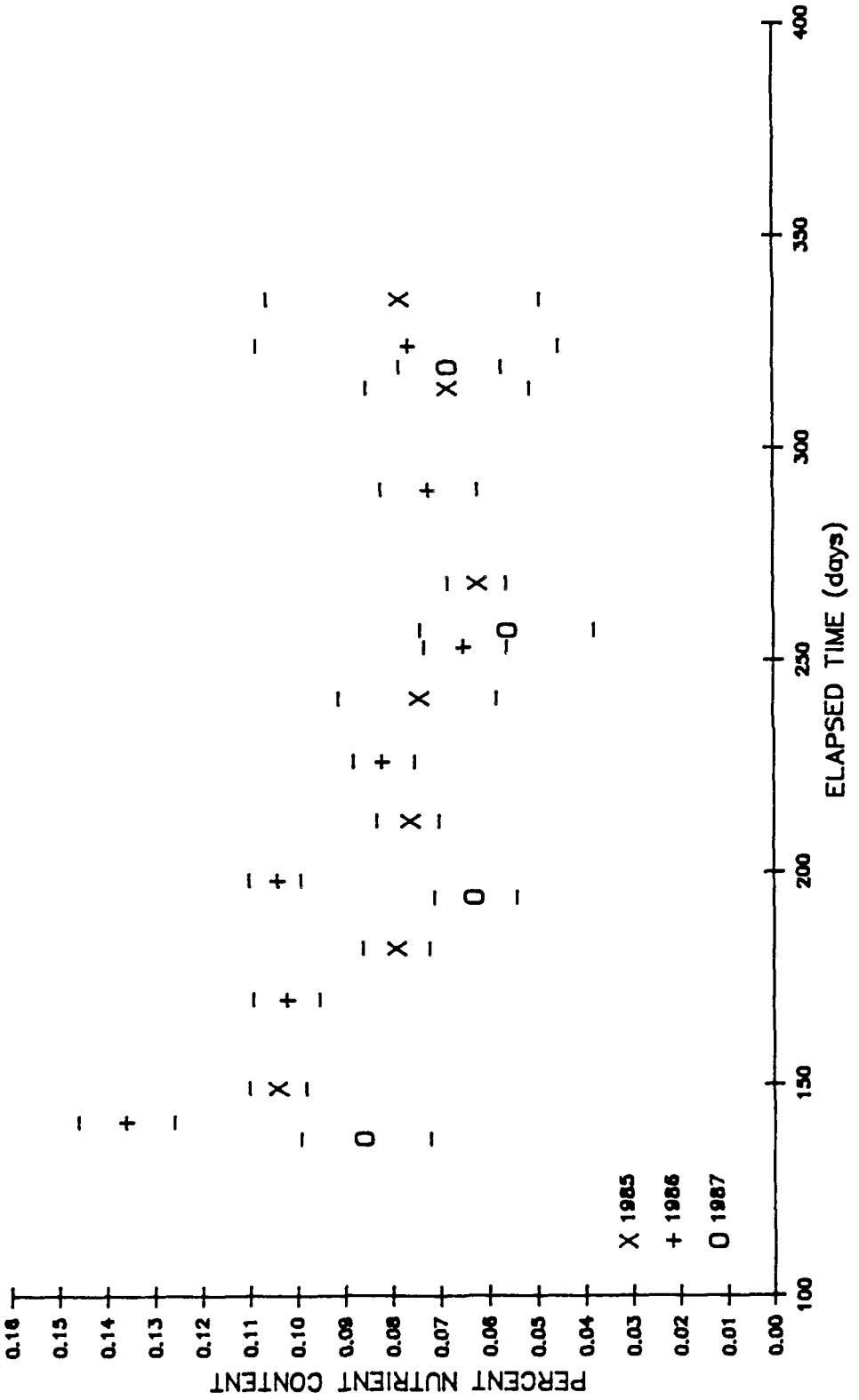

FIGURE 196. Percent magnesium content of bulk maple leaf samples retrieved from the ground unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

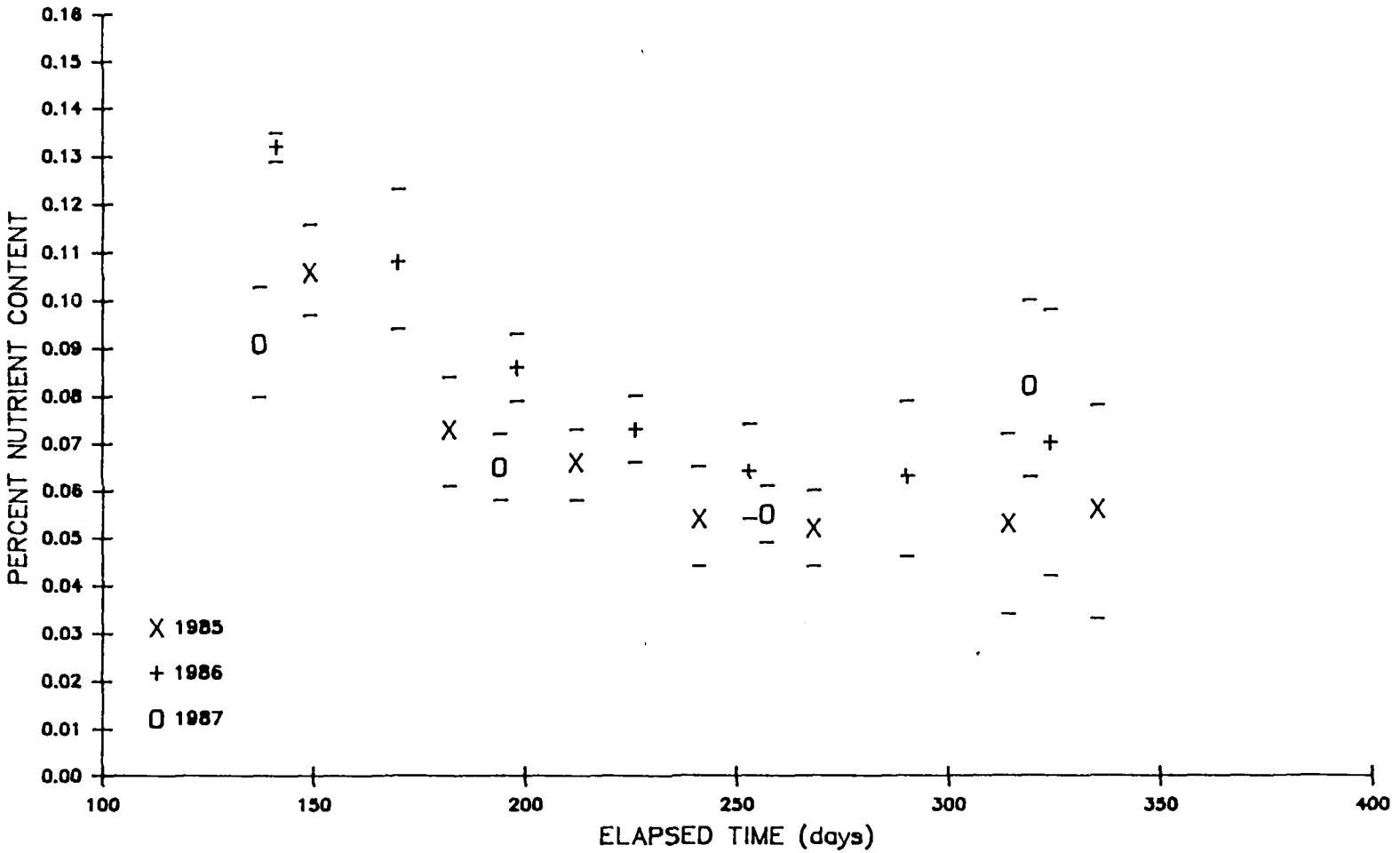

FIGURE 197. Percent magnesium content of bulk maple leaf samples retrieved from the antenna unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

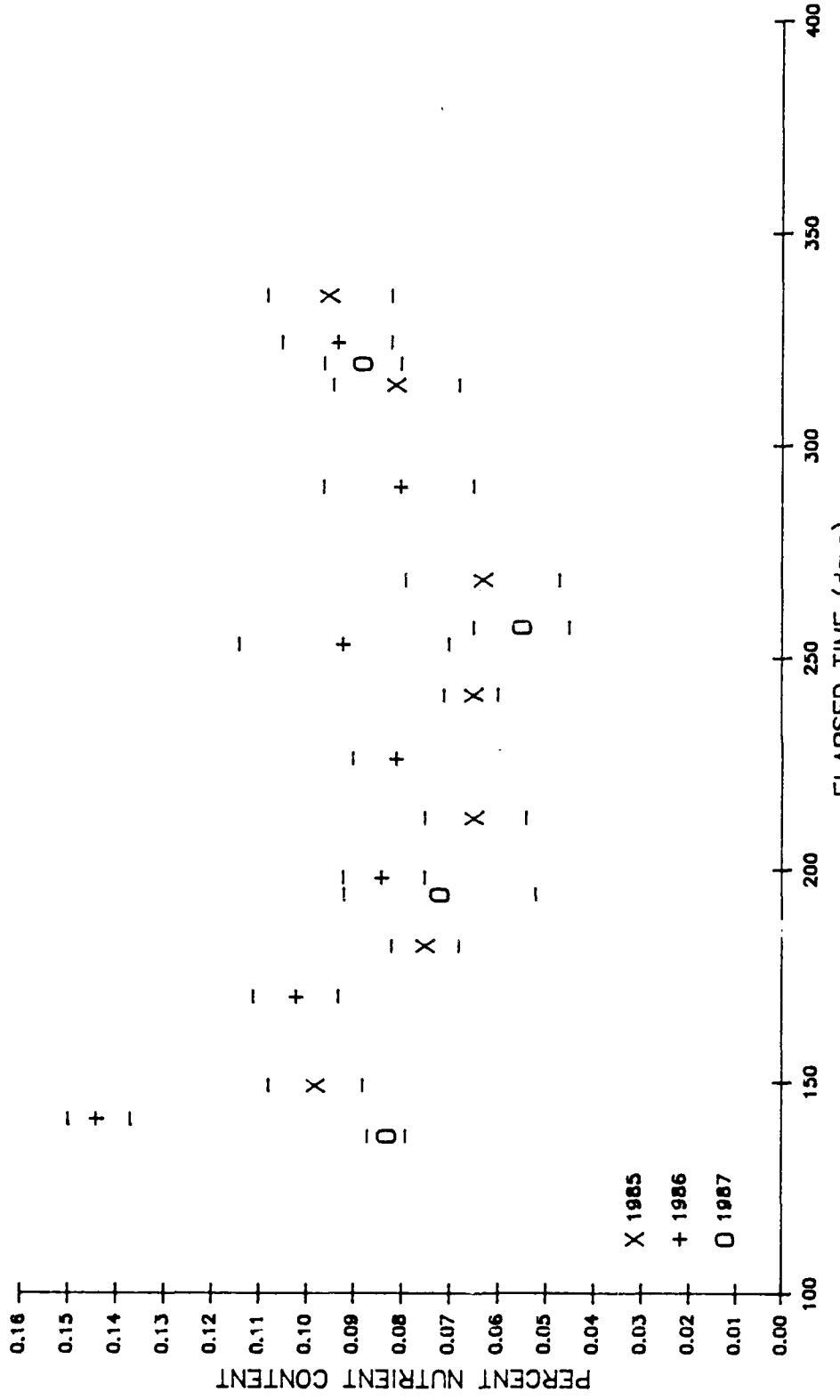

FIGURE 198. Percent magnesium content of bulk maple leaf samples retrieved from the control unit plantation during the 1984–1985, 1985–1986, and 1986–1987 experiments.

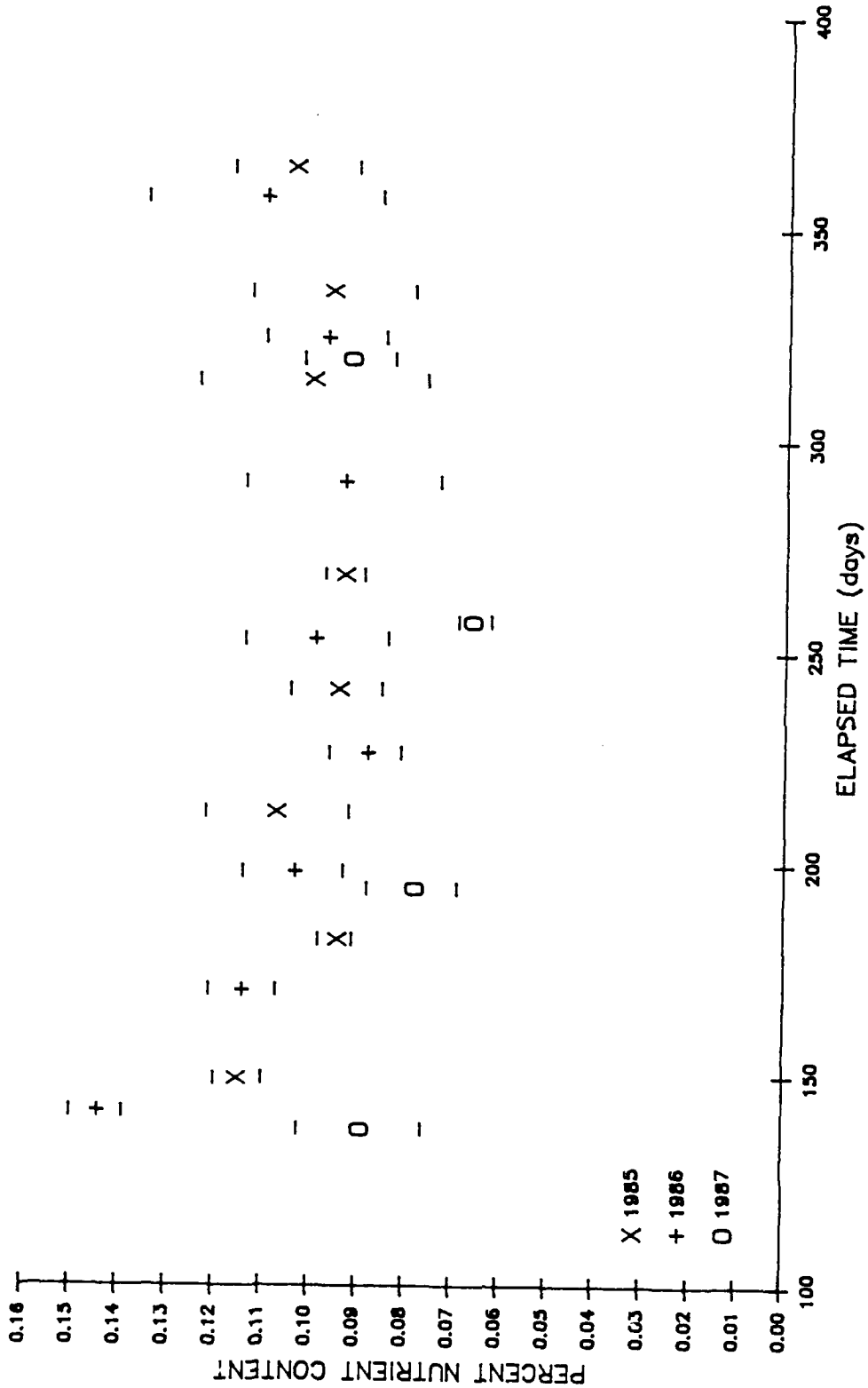

FIGURE 199. Percent magnesium content of bulk maple leaf samples retrieved from the antenna unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

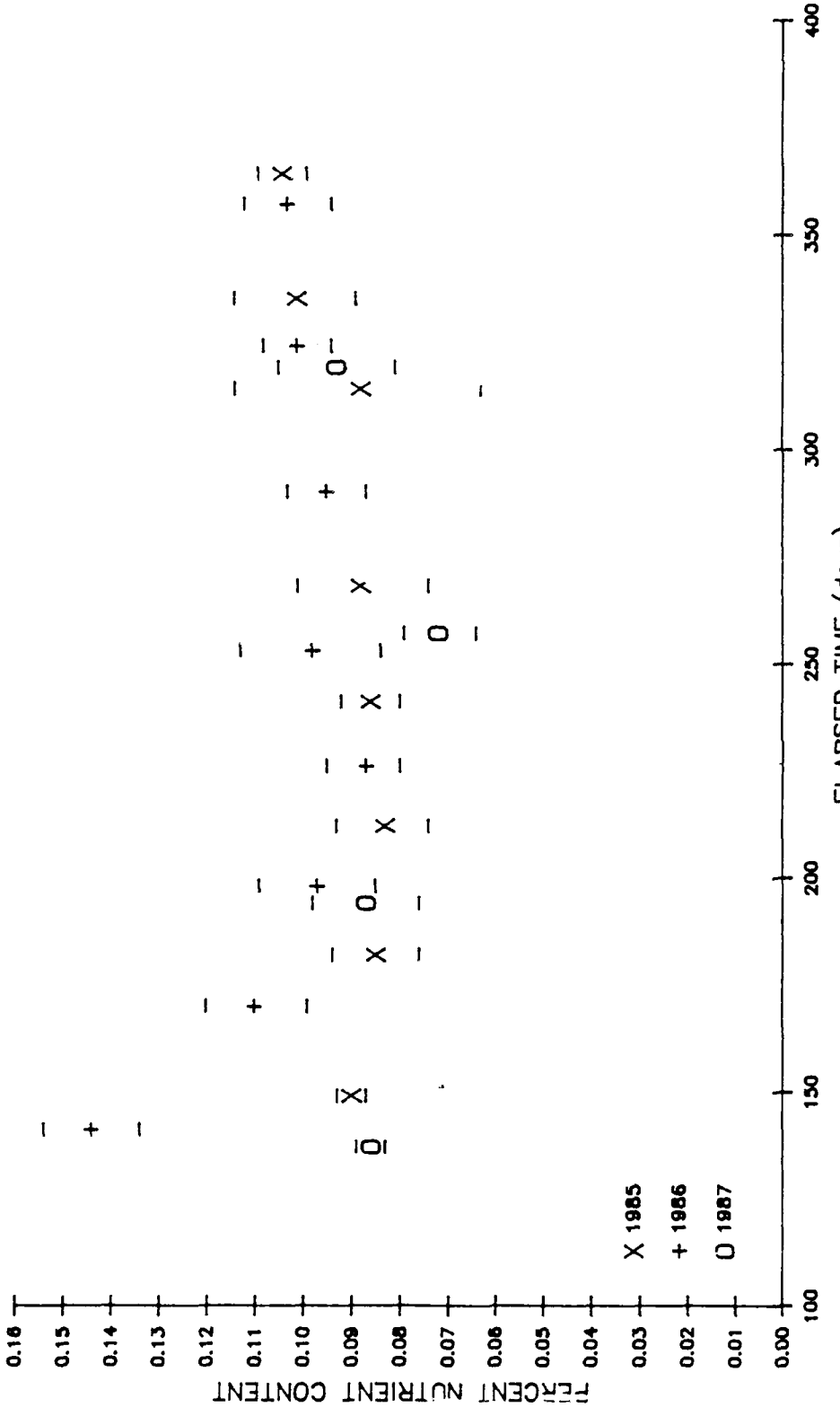

FIGURE 200. Percent magnesium content of bulk maple leaf samples retrieved from the control unit hardwood stand during the 1984–1985, 1985–1986, and 1986–1987 experiments.

Element 2: RED PINE SEEDLING RHIZOPLANE STREPTOMYCETES

Introduction

Streptomycetes have been implicated in the calcium and phosphorus nutrition of ectomycorrhizae and can influence mycorrhizosphere microbial population composition through production and excretion of compounds such as antibiotics, vitamins, amino acids, and hormones (Marx 1982, Keast and Tonkin 1983, Strzelczyk and Pokojska-Burdziej 1984, Strzelczyk et al. 1987). Streptomycetes have also been found to degrade calcium oxalate, cellulose, and lignin/lignocellulose in both coniferous and deciduous litter systems (Graustein et al. 1977, Crawford 1978, Knutson et al. 1980, Antai and Crawford 1981, McCarthy and Broda 1984). The sensitivity and value of the red pine mycorrhiza studies being conducted by the Herbaceous Plant Cover and Tree Studies ("Trees") project are greatly enhanced through quantitative study of the associated streptomycete populations. For instance, in cognate studies, we are finding that in vitro growth rates of several common mycorrhizal fungus species are differentially affected by certain streptomycete strains isolated from the mycorrhizoplane of ELF plantation red pine seedlings (Richter et al 1989).

The emphasis of this element during the 1988 sampling season continued to be the enumeration and characterization (into morphological types or morphotypes) of streptomycetes associated with the red pine mycorrhizal rhizoplane (i.e., washed mycorrhizal fine roots). As has been the case from 1985 through 1987, the mycorrhizal condition of red pine seedlings in the ground, antenna, and control site plantations has been followed on a monthly basis in 1988, from May through October, by staff of the "Trees" project. Samples of the red pine mycorrhizae collected and identified from each of the ELF study red pine plantations were provided to this study for analysis of streptomycete population dynamics. As in previous years, a single mycorrhiza morphology type, designated type 3, has been studied. Type 3 mycorrhizae continue to predominate in all three ELF study plantations, probably because they are most often caused by species of Laccaria and/or Thelephora which occur naturally both in the study area and in the nursery from which the seedlings were originally obtained ("Trees" project, Draft Annual Report 1988, Element 5. Mycorrhiza Characterization and Root Growth, pages 147-161).

As in previous years, six washed root samples (for macerate plate counts) were analyzed per month from each of the three ELF study site red pine plantations. In addition to comparing data among plantations and sampling dates, the streptomycete level and morphotype data obtained during the 1988 sampling season were compared to data obtained for 1985 through 1987. The capabilities of the streptomycete morphotypes recovered to degrade calcium oxalate, cellulose, and lignocellulose were also determined.

Methods

Six washed mycorrhizal red pine fine root samples were collected and prepared monthly from late May to mid October at the ground, antenna, and control site ELF study plantations. Five seedlings are excavated per month on each of the three plots comprizing each plantation. Two independent composite samples are derived from two to three of the seedlings from each plot. The same plantation plots were sampled in 1988 as in 1984 through 1987. These samples were stored at 4°C and processed within 24 hours of receipt by the Environmental Microbiology lab in the Department of Biological Sciences. Approximately 9 days were required for processing of field samples from the time root samples are collected in the field to the delivery of washed root samples for streptomycete analysis. All samples were refrigerated over this period of time. The single exception to date from this protocol occurred when the 11 October 1988 root samples were not delivered until 4 November. They were processed immediately on receipt.

Using flame-sterilized forceps, 0.1 g (wet weight) of washed roots was placed in 9.9 ml of sterile buffer (0.01 M phosphate buffer, pH 7.2) and homogenized in a flame-sterilized 30 ml blender. This mixture was then transferred to a sterile, screw-cap test tube. Subsequent serial dilutions were made using the same type of sterile buffer. Two larger portions of the washed roots (about 0.5 g each) were transferred to separate pre-weighed aluminum pans and weighed; these portions were then placed in a drying oven (60°C) for determination of dry weights.

As in the earlier studies, all washed root samples (after preparation and appropriate serial dilution) were spread-plated onto starch casein agar (SCA) in 100 x 15 mm petri dishes. Cycloheximide (50 mg/l) and nystatin (50 mg/l) were added to the SCA to prevent fungal growth (Andrews and Kennerly 1979, Goodfellow and Dawson 1978). Three dilutions (in duplicate) were spread-plated per sample. All plates were incubated at 20°C. Total numbers of streptomycete colonies were determined after 14 days incubation.

After enumeration, individual streptomycete colonies were characterized to determine the number of morphotypes per sample. All colonies with the same characteristics (i.e., presence/absence of diffusable pigment, presence/absence of aerial mycelium, color of aerial mycelium and any diffusable pigment, and reverse colony color) were considered to represent one morphological type or strain (Keast et al. 1984). Throughout the study, several colonies per streptomycete morphotype have been maintained in pure culture for further study. In order to evaluate the streptomycetes' potential contribution to mycorrhiza development and root growth, additional tests were conducted to evaluate degradation of calcium oxalate (Jayasuriya 1955, Knutson et al. 1980), cellulose (Smith 1977), and lignocellulose (Sutherland 1985). Not only the numbers of distinct streptomycete morphotypes found in the 1988 samples, but also their recurrence, were compared to observations from similar

samples from 1984 through 1987, to determine if some of the same types are present after the red pine seedlings have been in the field four years or more, and to determine whether the same types are/were present in all three ELF study site plantations.

Data for streptomycete levels and morphotype numbers, based on the SCA plate counts, were transformed to $\log_{10}$ for statistical analysis (Orchard 1984). All statistical analyses were conducted on the mainframe computer using PROC GLM of the Statistical Analysis System (SAS 1985). Two-way analysis of variance was used to compare sampling dates and study site plantations within 1988. Three-way analysis of variance was used to compare years (1985 through 1988) as well as dates and plantations (Zar 1984). Wherever these analyses showed significant differences ($\alpha = 0.05$) between years, sites or sampling dates, Tukey's H.S.D. procedure was used to conduct multiple comparisons between years, sites and/or sampling dates (Dowdy and Wearden 1983).

Covariates are being used to help explain differences in streptomycete levels and/or morphotype numbers among years, plantations, and sampling dates. For this report, nearly all of the covariates tested were weather-related variables, due to their apparent independence of ELF field influence. Wherever covariance analysis detected significant differences, the results of pairwise comparisons (SAS, PROC GLM, least squares means option) are presented. The capability of our experimental design to detect changes in mean values for either streptomycete levels or morphotype numbers is approximated, by using the 95 percent confidence interval for each sample mean (least squares means and standard errors, in the case of covariance analysis) to calculate the minimum detectable change (expressed as a percentage of each sample mean).

Description of Progress

Detailed information on the 1988 red pine seedling mycorrhiza populations studied here can be found in the Draft Annual Report of the "Trees" project (Element 5, pages 147-161). As noted earlier, one mycorrhiza morphology type (Type 3) predominated at all three plantations during the 1988 sampling season, as has been the case since plantation establishment in 1984. The numbers of mycorrhizae (both overall and Type 3) per gram of sampled red pine root weight in 1988, however, were lower than in previous years, for most site/month comparisons among years. Covariance analysis using precipitation-related weather variables explained differences among sites.

Data for 1988 streptomycete levels and morphotype numbers associated with washed type 3 mycorrhizal fine roots are presented in Tables 142 and 143 as 1) the mean, 2) the standard error of the sample mean, and 3) the minimum detectable difference between sample means based on 95 percent confidence intervals for six samples per plantation. The relevant ANOVA statistics for levels and morphotype numbers are presented in Tables 144 and 145, respectively. There was no significant

Table 142. Levels of streptomycetes (x 10^5) isolated from washed type 3 red pine mycorrhizal fine roots at each of the three ELF study plantations during 1988.

Sampling Date	Sampling Site								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	%[c]	Mean	S.E.	%	Mean	S.E.	%
27 May 1988	3.4	0.45	34	3.6	0.40	29	3.2	0.36	29
21 June 1988	3.8	0.52	35	3.4	0.34	26	4.5	0.33	19
19 July 1988	4.8	0.38	20	4.1	0.22	14	5.0	0.26	13
16 Aug. 1988	5.3	0.32	16	4.8	0.29	16	4.7	0.40	22
13 Sept. 1988	6.0	0.20	9	6.0	0.28	12	6.0	0.23	10
11 Oct. 1988	1.7	0.30	45	1.8	0.38	54	2.2	0.30	35

a/ mean value (per gram soil, o.d.w.) for six root samples per plot, each sample representing the composited roots of 2-3 red pine seedlings
b/ standard error of the mean
c/ estimated level of population change which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.025,5} *$ S.E./Mean, and expressed as a percentage of the sample mean

Table 143. Levels of streptomycete morphotypes isolated from washed type 3 red pine mycorrhizal fine roots at each of the three ELF study plantations during 1988.

Sampling Date	Sampling Site								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	%[c]	Mean	S.E.	%	Mean	S.E.	%
27 May 1988	2.7	0.21	19	3.3	0.33	26	3.5	0.43	32
21 June 1988	2.3	0.21	23	2.8	0.40	37	3.7	0.33	23
19 July 1988	2.8	0.48	44	3.3	0.61	48	2.8	0.48	44
16 Aug. 1988	3.3	0.42	32	2.7	0.49	47	3.3	0.56	44
13 Sept. 1988	3.7	0.56	39	5.2	0.31	15	4.2	0.31	19
11 Oct. 1988	2.7	0.21	19	2.7	0.21	19	2.7	0.33	31

a/ mean value for six root samples per plot, each sample representing the composited roots of 2-3 red pine seedlings
b/ standard error of the mean
c/ estimated level of population change which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as $t_{0.025,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 144. ANOVA table for detection of differences in 1988 levels of streptomycetes associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by month (May - October), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	7	3.17		31.69	0.0001	0.69
Month	5		3.13	43.87	0.0001	
Plantation	2		0.04	1.23	0.2962	
Error	100	1.43				
Corrected Total	107	4.60				

Table 145. ANOVA table for detection of differences in numbers of streptomycete types associated in 1988 with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by month (May - October), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	7	0.54		4.19	0.0004	0.23
Month	5		0.46	5.01	0.0004	
Plantation	2		0.08	2.13	0.1247	
Error	100	1.83				
Corrected Total	107	2.37				

difference during 1988 in either streptomycete levels ($p = 0.2962$) or morphotype numbers ($p = 0.1247$) among the control, antenna and ground site plantations. There was a significant seasonal effect on both levels ($p = 0.0001$)and morphotype numbers ($p = 0.0004$). Tukey's H.S.D. multiple comparison tests of the 1988 streptomycete level data (Table 146), indicated that October levels were significantly lower than those of any other month, and that May levels were lower than those of July through September. September levels were higher than those of June as well. Estimated detectable differences (using ANOVA) for streptomycete levels, among years, sites, and sampling dates were approximately 1 percent of the mean (Table 146). Morphotype numbers changed little through August, were highest in September, and then lower again in October (Table 147). September morphotype numbers were significantly higher than those for any other month. The relatively large detectable difference estimates for morphotype numbers data (approximately 10 percent for sites and 20 to 30 percent for months) indicates that these data are much less precise than are levels data. However, in light of the low average number of morphotypes encountered per sample (3 - 4; Table 143), loss of a single morphotype would still be detectable.

The seasonal patterns for levels and morphotypes data are presented as Figures 201 - 208, for $\log_{10}$-transformed data from 1988, 1987, 1986, and 1985. The seasonal patterns of both levels and morphotypes for 1987 and 1988 show similar trends, peaking slightly in September and dropping off significantly in October. This represents a departure from the seasonal patterns of 1985 and 1986, when earlier months provided significantly greater values than did later months. However, the lowest values for levels for all years were typically in October. The observed differences in monthly patterns, before ANACOV, between 1985-86 and 1987-88, may be related to the growth and maturation of the red pine seedlings during this same time period. The possibility of such relationships will be investigated.

Three-way ANOVA tables for statistical comparisons between the 1985, 1986, 1987, and 1988 streptomycete levels and morphotype numbers are presented in Tables 148 and 149, respectively. With both data sets, significant differences were found among years and months, but not between plantations. Results of multiple comparison tests are presented in Tables 150 and 151, for levels and morphotype numbers respectively. Streptomycete levels for 1985 and 1986 were not significantly different, but were significantly lower than the 1987 and 1988 levels, which also were similar. The only month with significantly different levels was October. The numbers of observed morphotypes declined from 1985 to 1986, and from 1986 to 1987. No further decline, from 1987 to 1988, was apparent. This decline could represent establishment and persistence of those streptomycete types most capable of growth and survival with the red pine mycorrhizae at these sites. Morphotype numbers encountered in October were significantly lower than those found in May or June, and August numbers were significantly lower than

Table 146. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 144.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]					
Month					1	2	3	4	5
May	5.51	0.028	1.00	May					
June	5.57	0.028	0.98	June					
July	5.66	0.028	0.97	July	*				
August	5.69	0.028	0.96	Aug	*				
September	5.77	0.028	0.95	Sept	*	*			
October	5.24	0.028	1.05	Oct	*	*	*	*	*
Plantation							G		A
Ground	5.60	0.020	0.98	Ground					
Antenna	5.55	0.020	0.99	Antenna					
Control	5.57	0.020	0.98	Control					

a/ mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Tukey's H.S.D.

Table 147. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 145.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]
Month				1 2 3 4 5
May	0.49	0.032	26.80	May
June	0.45	0.032	29.18	June
July	0.45	0.032	29.18	July
August	0.48	0.032	27.36	Aug
September	0.62	0.032	21.18	Sept * * * *
October	0.42	0.032	23.04	Oct *
Plantation				G C
Ground	0.50	0.023	9.02	Ground
Antenna	0.50	0.023	9.02	Antenna
Control	0.44	0.023	10.25	Control

a/ mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Tukey's H.S.D.

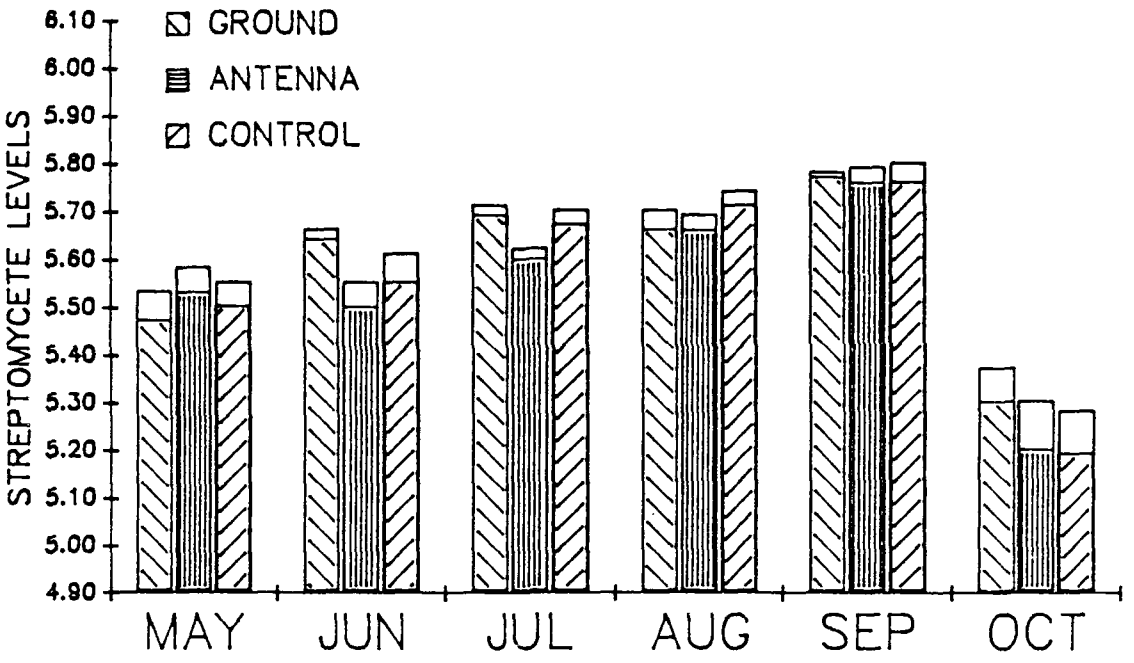

FIGURE 201. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycetes in the three study plantations during 1988.

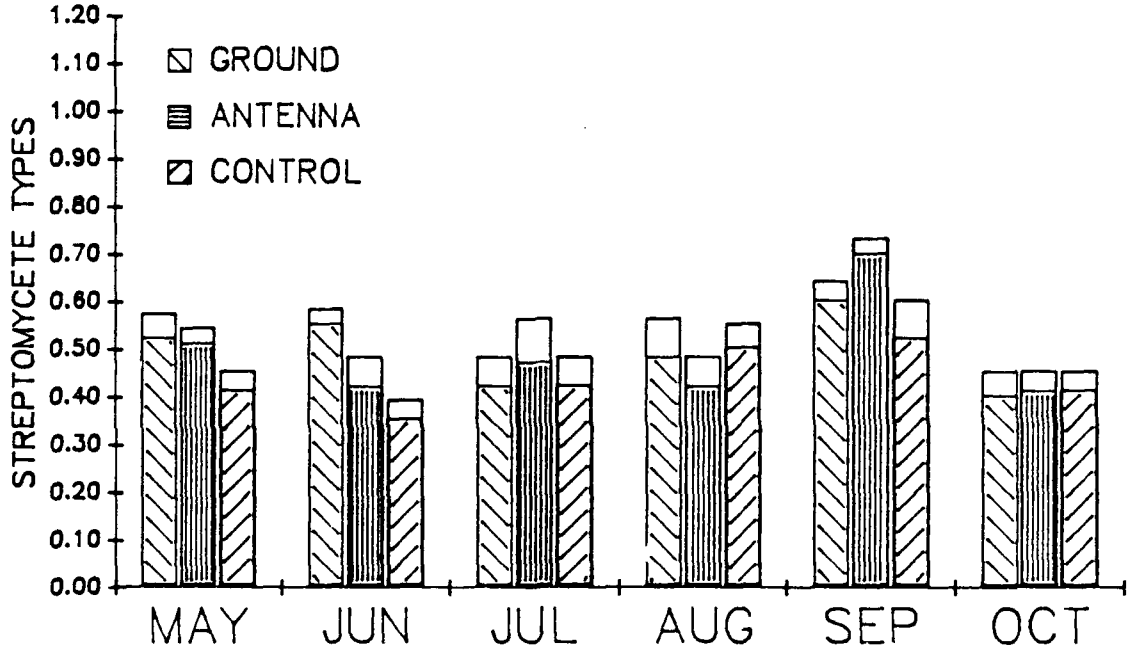

FIGURE 202. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycete morphotypes in the three study plantations during 1988.

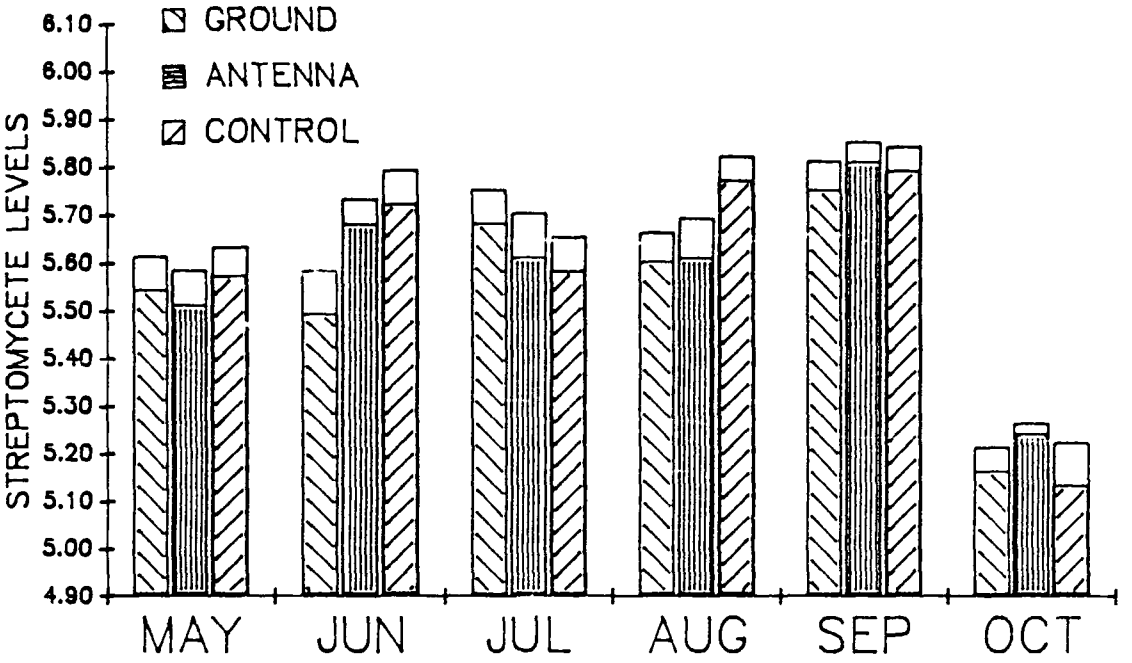

FIGURE 203. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycetes in the three study plantations during 1987.

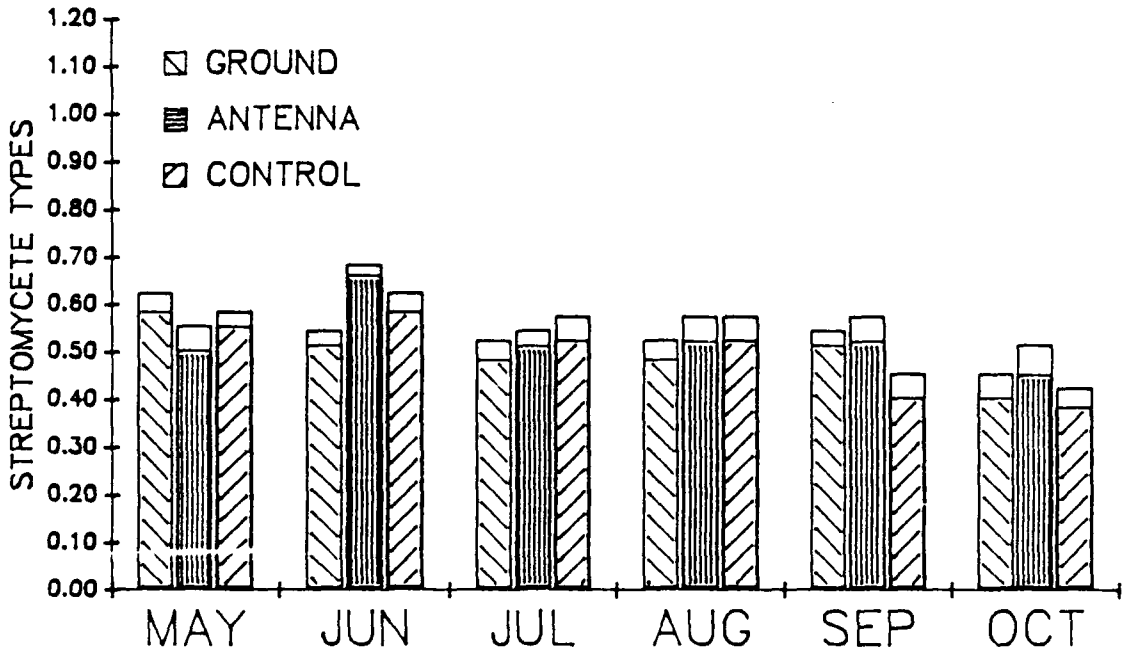

FIGURE 204. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycete morphotypes in the three study plantations during 1987.

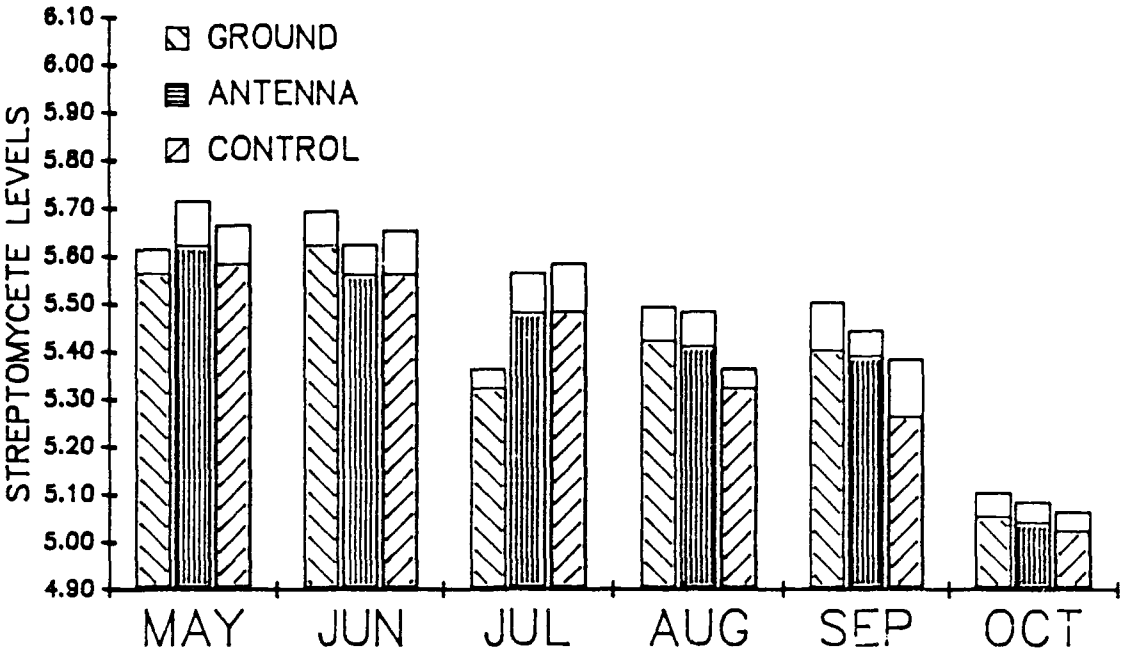

FIGURE 205. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycetes in the three study plantations during 1986.

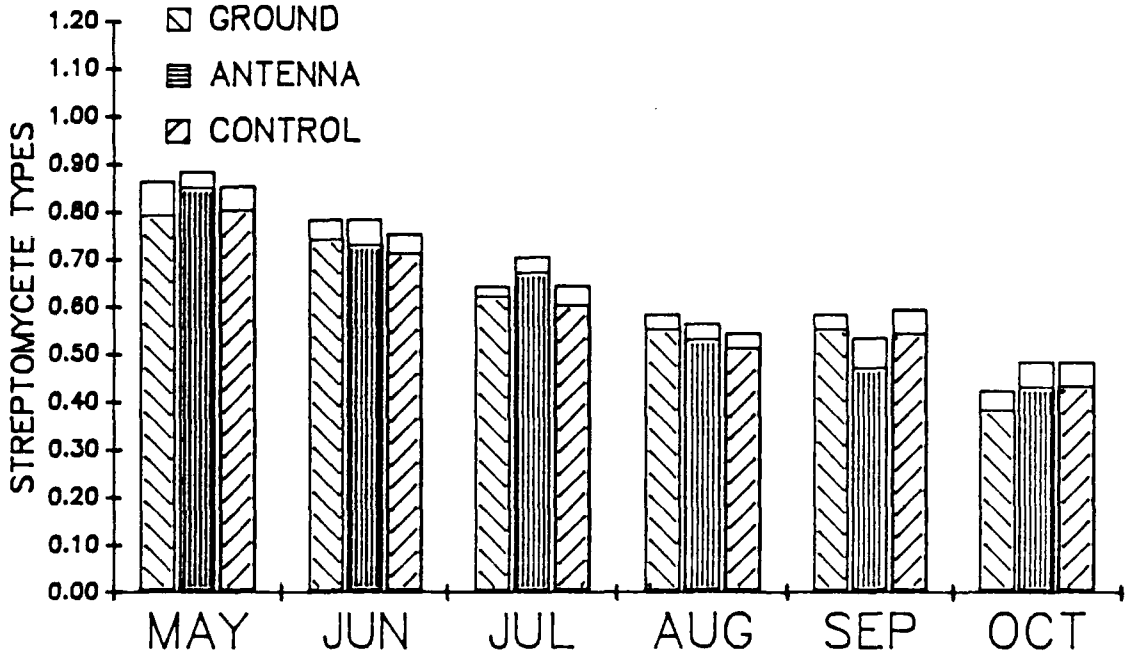

FIGURE 206. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycete morphotypes in the three study plantations during 1986.

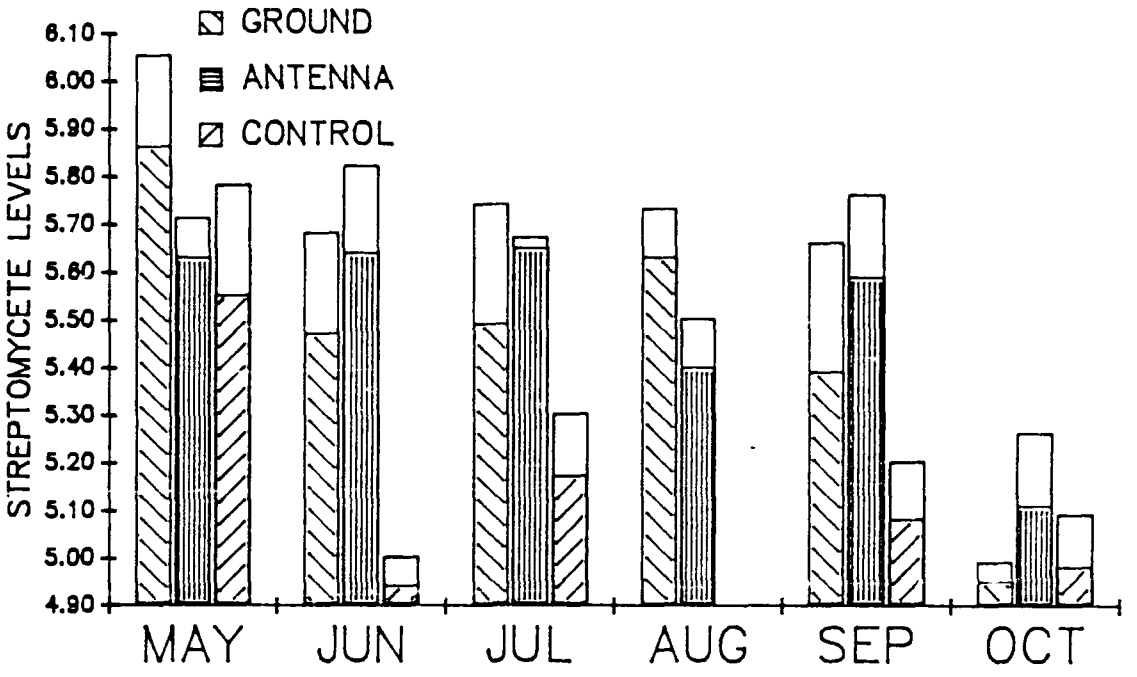

FIGURE 207. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycetes in the three study plantations during 1985.

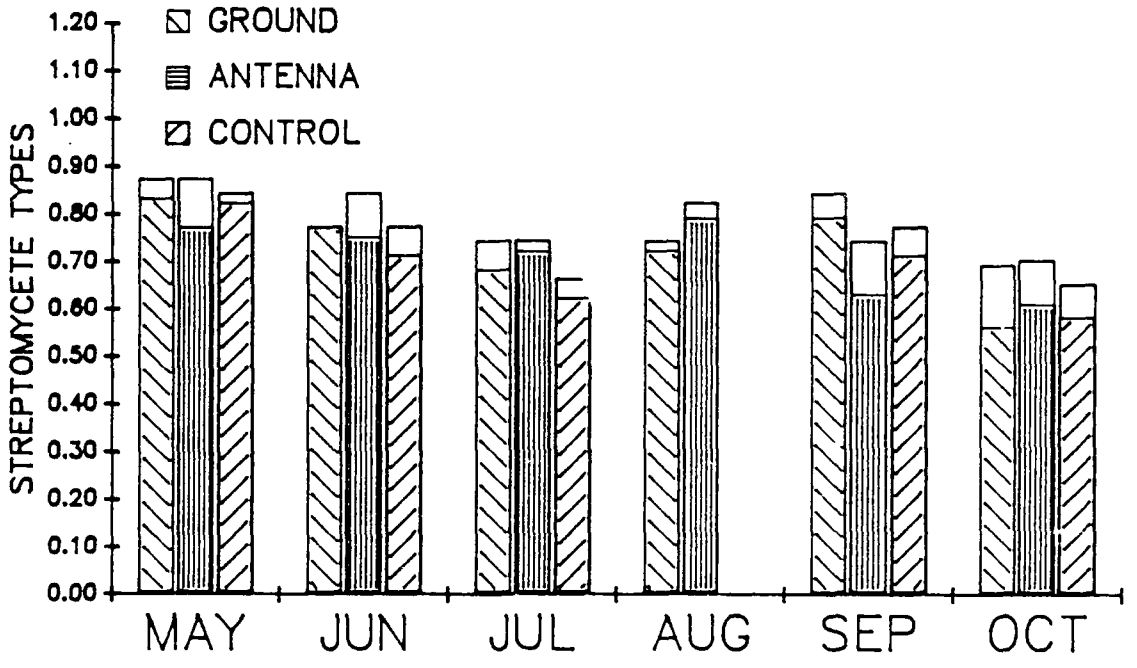

FIGURE 208. Seasonal pattern of recovery (mean + s.e.) for levels of mycorrhizoplane streptomycete morphotypes in the three study plantations during 1985.

Table 148. ANOVA table for detection of differences in streptomycete levels associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by year and month (May - October), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	10	12.98		32.81	0.0001	0.47
Year	3		2.80	23.60	0.0001	
Month	5		9.99	50.49	0.0001	
Plantation	2		0.15	1.90	0.1504	
Error	364	14.40				
Corrected Total	374	27.38				

Table 149. ANOVA table for detection of differences in numbers of streptomycete types associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by year and month (May - October), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	10	4.16		24.91	0.0001	0.41
Year	3		2.49	49.64	0.0001	
Month	5		1.56	18.69	0.0001	
Plantation	2		0.07	2.17	0.1157	
Error	364	6.08				
Corrected Total	374	10.24				

Table 150. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 148.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]	
Year					5 6 7
1985	5.40	0.028	1.02	1985	
1986	5.40	0.019	0.69	1986	
1987	5.58	0.019	0.67	1987	* *
1988	5.57	0.019	0.67	1988	* *
Month					1 2 3 4 5
May	5.56	0.025	0.88	May	
June	5.55	0.025	0.88	June	
July	5.54	0.025	0.88	July	
August	5.56	0.026	0.92	Aug	
September	5.59	0.025	0.88	Sept	
October	5.13	0.025	0.96	Oct	* * * * *
Plantation					G A
Ground	5.50	0.018	0.64	Ground	
Antenna	5.51	0.018	0.64	Antenna	
Control	5.46	0.018	0.65	Control	

a/ mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Tukey's H.S.D.

Table 151. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 149.

Source of Variation	Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]						
Year					5		6		7	
1985	0.72	0.018	4.90	1985						
1986	0.62	0.012	3.79	1986	*					
1987	0.51	0.012	4.61	1987	*		*			
1988	0.48	0.012	4.90	1988	*		*			
Month					1	2	3	4	5	
May	0.67	0.016	4.68	May						
June	0.64	0.016	4.90	June						
July	0.57	0.016	5.50	July						
August	0.56	0.017	5.95	Aug	*					
September	0.59	0.016	5.32	Sept						
October	0.46	0.016	6.82	Oct	*	*				
Plantation							G		C	
Ground	0.59	0.012	3.99	Ground						
Antenna	0.60	0.012	3.92	Antenna						
Control	0.56	0.012	4.20	Control						

a/ mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, Tukey's H.S.D.

May numbers. The detectable difference levels for this $\log_{10}$-transformed 4-year data set as a whole were about 1 percent for streptomycete levels and between 3 and 6 percent for morphotype numbers.

Correlation analyses were conducted as a first step in exploring relationships of seasonal patterns of streptomycete levels and morphotype numbers with weather, other environmental, and vegetation-associated variables. Over 30 variables related to temperature, precipitation, soil moisture, nutrient status, rhizosphere soil pH, previous forest cover, mycorrhizae levels, and seedling growth and vigor were analyzed in order to determine their potential value as covariates to explain differences among years and months detected by ANOVA. Some of the variables having p values less than 0.05 and correlation coefficients greater than $|0.3000|$ were selected for the initial analysis of covariance (ANACOV) studies. Priority has been given to weather-related variables, which are presumed to be independent of direct ELF field influence. Temperature- and precipitation-related variables were evaluated in two basic forms: 1) as the running totals for the growing season previous to each sampling date, and 2) as totals for the 30 day period previous to each sampling date.

The first round of covariates tested with 1985-1988 streptomycete levels and morphotype numbers included only weather-related variables. For streptomycete levels, ANACOV (Table 152) explained all differences between years which had been detected by ANOVA (Tables 148 and 150), without raising detectable differences inordinately (Table 154). The corresponding F values for overall differences between plantations and monthly sampling dates were also reduced, providing better explanation of plantations. Use of the covariate PR.1RT also had the most effect in explaining both differences in mycorrhizae levels among sites and the year X site interaction ("Trees" project, Draft Annual Report 1988, pp. 147-161). This first ANACOV indicates that, when the weather-related covariates are taken into account, mean streptomycete levels decline significantly as seasons progress. For morphotype numbers, ANACOV (Table 153) explained a number of the differences between years (Table 155) which were detected by ANOVA (Tables 147 and 151), with only a modest increase in detectable differences to 8 - 10 percent. However, since the number of morphotypes observed is quite small (Table 143), loss of a single morphotype would likely be detected. Mean numbers of morphotypes observed, adjusted for the covariates (Table 155), appear to be declining with plantation age (while total population levels remain stable). Differences between sampling dates were explained, but with greatly increased detectable differences.

Because of our success in explaining differences in streptomycete levels among years and plantations using weather-related covariates, we did not find it necessary to analyze the streptomycete levels data without the October sampling date, as we did for the 1987 annual report. We did,

Table 152. Covariance analysis table far detection of differences in streptomycete levels associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by year and by month (May - October), using ATDDRT, PRWRT, and PR.1RT as covariates[a].

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	14.87		33.02	0.0001	0.54
Year	3		0.16	1.50	0.2140	
Month	5		4.98	28.75	0.0001	
Plantation	2		0.04	0.55	0.5788	
PR.1RT	1		0.53	15.18	0.0001	
PRWRT	1		1.00	28.72	0.0001	
ATDDRT	1		0.31	8.82	0.0032	
Error	361	12.51				
Corrected Total	374	27.38				

a/ ATDDRT is the running total number of degree days for the year 5 cm below the soil surface (4.4°C basis); PRWRT is the running total of rainfall for the year; PR.1RT is the running total of the number of days with precipitation events delivering at least 0.1 inch of rain.

Table 153. Covariance analysis table for detection of differences in numbers of streptomycete types associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by year and month (May - October), using ST5DDRT, PRWRT, and PR.01RT as covariates[a].

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	4.72		23.76	0.0001	0.46
Year	3		2.48	54.15	0.0001	
Month	5		0.35	4.62	0.0004	
Plantation	2		0.00	0.05	0.9498	
PRWRT	1		0.45	29.25	0.0001	
PR.01RT	1		0.25	16.13	0.0001	
ST5DDRT	1		0.00	0.28	0.5942	
Error	361	5.52				
Corrected Total	374	10.24				

a/ ST5DDRT is the running total of degree days for the year 5 cm below the soil surface (4.4°C basis); PRWRT is the running total of rainfall for the year; PR.01RT is the running total of the number of days with precipitation events delivering at least 0.01 inch of rain.

Table 154. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 152.

Source of Variation	Adjusted Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]
Year				5 6 7
1985	5.41	0.051	1.85	1985
1986	5.51	0.031	1.10	1986
1987	5.52	0.030	1.06	1987
1988	5.52	0.025	0 89	1988
Month				1 2 3 4 5
May	6.05	0.174	5.64	May
June	5.88	0.113	3.77	June *
July	5.63	0.042	1.46	July * *
August	5.38	0.056	2.04	Aug * * *
September	5.27	0.115	4.28	Sept * * *
October	4.72	0.153	6.35	Oct * * * * *
Plantation				G A
Ground	5.50	0.023	0.82	Ground
Antenna	5.50	0.019	0.68	Antenna
Control	5.47	0.024	0.86	Control

a/ adjusted mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, least squares means pairwise comparisons

Table 155. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 153.

Source of Variation	Adjusted Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]				
Year					5	6	7	
1985	0.70	0.035	9.80	1985				
1986	0.62	0.025	7.90	1986				
1987	0.55	0.028	9.98	1987	*			
1988	0.45	0.020	8.71	1988	*	*	*	
Month					1	2	3	4 5
May	0.65	0.118	35.58	May				
June	0.63	0.078	24.27	June				
July	0.56	0.029	10.15	July				
August	0.54	0.036	13.07	Aug				
September	0.60	0.082	26.79	Sept				
October	0.50	0.116	45.47	Oct				*
Plantation							G	C
Ground	0.58	0.012	4.06	Ground				
Antenna	0.58	0.012	4.06	Antenna				
Control	0.58	0.012	4.06	Control				

a/ adjusted mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, least squares means pairwise comparisons

however, include the pH of rhizosphere soil and plant moisture stress data obtained for the sampled seedlings with a Scholander pressure bomb, along with weather-related covariates, in the second round of covariate analyses. As sole covariate, pH greatly lowered the F statistic value for site comparisons of streptomycete levels. Addition of pH to the list of covariates, however, did not greatly improve the analysis of levels, and did not improve the analysis of morphotype numbers at all. Addition of plant moisture stress (PMS) as a covariate did not provide improved explanation of differences in observed morphotype numbers among years, sites, or months. Nevertheless, addition of PMS as a covariate greatly improved explanation of differences in streptomycete levels between years, reduced the F value for the differences among months, and continued to explain differences among plantations (Table 156). Detectable differences in levels remain low (Table 157). While we are not certain at this time whether or not plant moisture stress data are statistically independent of ELF fields, it does appear that further use of ANACOV will continue to be a useful tool for explaining the influences of environmental variables on mycorrhizoplane streptomycete levels and morphotype numbers.

Morphotype Distribution and Characterization

Streptomycete morphotypes characterized during the 1988 sampling season from type 3 washed mycorrhizal fine roots are presented in Table 158. The same morphotypes were found in 1988 as in 1987, with a few differences in incidence between the sampling seasons. As in 1987 and previous years, morphotypes B and F were detected at each plantation on each sampling date, often as the predominant types. Morphotypes D, J, K, S, and T were also commonly detected, as in 1987. In particular, the incidences of morphotypes A, C, and O decreased, but those of morphotypes U and W increased. There were similarities in common morphotype incidence among those plantation site samples consisting only of mycorrhizal type 3 fine roots, i.e., 1986 through 1988. For the control site plantation, the incidence of B, F, and A were about equal for all three years, with some increases in morphotype J and decreases in D in 1988. Morphotypes B, D, F, J, K, and U were commonly found at the antenna site plantation in 1986 through 1988. An increase in morphotype N incidence was found in 1988; the levels of morphotype A were similar to those reported in 1986. Similar morphotypes to the antenna site plantation were common with the 1986 through 1988 ground site plantation samples, i.e., morphotypes B, F, J, K, and S. The incidences of morphotypes A, D, and T were similar to those found in 1986, while the incidence of morphotype U was higher than in 1986 or 1987.

From two to five streptomycete isolates representing each of the 19 morphotypes detected during 1988 (Table 158) were tested for ability to degrade calcium oxalate, cellulose, and lignocellulose. Of the 88 isolates tested, 73 percent, 75 percent, and 72 percent degraded these three substrates,

Table 156. Covariance analysis table for detection of differences in streptomycete levels associated with type 3 red pine mycorrhizae (log_{10}-transformed data), among the three plantation subunits, by year and month, using ATDDRT, PRWRT, PR.1RT, and PMS as covariates[a].

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	3.29		6.82	0.0001	0.25
Year	3		0.00	0.01	0.9993	
Month	4		0.51	3.42	0.0095	
Plantation	2		0.06	0.81	0.4482	
ATDDRT	1		0.46	12.38	0.0005	
PRWRT	1		0.60	16.18	0.0001	
PR.1RT	1		0.39	10.41	0.0014	
PMS	1		0.01	0.22	0.6422	
Error	262	9.72				
Corrected Total	275	13.02				

[a] ATDDRT is the running total of air temperature degree days for the year (4.4°C basis); PRWRT is the running total of rainfall for the year; PR.1RT is the running total of the number of days with precipitation events delivering at least 0.1 inch of rain; PMS is a measure of plant moisture stress obtained with use of the Scholander pressure bomb.

Table 157. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 156.

Source of Variation	Adjusted Mean[a]	Standard Error[b]	Detectable Difference[c]	Significant Differences[d]	
Year					5 6 7
1985	5.49	0.062	2.21	1985	
1986	5.49	0.040	1.43	1986	
1987	5.49	0.061	2.18	1987	
1988	5.49	0.042	1.50	1988	
Month					1 2 3 4 5
May	6.17	0.184	5.84	May	
June	5.88	0.093	3.10	June	*
July	5.48	0.032	1.14	July	* *
August	5.06	0.146	5.66	Aug	* * *
September	4.86	0.227	9.16	Sept	* * * *
Plantation					G A
Ground	5.51	0.025	0.89	Ground	
Antenna	5.50	0.028	1.00	Antenna	
Control	5.45	0.049	1.76	Control	

a/ adjusted mean of transformed data
b/ standard error of the least squares mean, provided by the Least Squares Means option of SAS Proc GLM
c/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = 0.05$), calculated as ($t_{0.05,n-1}$ * S.E. / Mean), and expressed as a percentage of the sample mean
d/ $\alpha = 0.05$, least squares means pairwise comparisons

Table 158. Streptomycete morphotypes associated with washed mycorrhizal type 3 fine roots.

Sampling Date (1988)	Study Site[a]	Streptomycete Morphotype																			
		A	B	C	D	F	G	H	J	K	N	O	P	Q	R	S	T	U	V	W	
27 May	C		X^b			X^cX			X			X				X			X		
	A		X^c		X	X^bX			X	X^bX^b					X	X^b		X	X		
	G	X	X^c		$X^bX^cX^bX$				X	X	X^b				X	X^bX^bX				X	
21 June	C		X^b		X	X^b												X	X^bX		
	A		X^c		X^bX^b				X	X	X					X				X	
	G		X^cX^bX			X^b			X^bX		X^bX				X^b		X^bX^b			X	
19 July	C		X^b		X	X			X^b			X				X	X^b				
	A	X	X^bX		X^cX^b		X			X^bX				X	X		X^b		X	X^b	
	G		X^b		X	X	X		X	X^b		X				X^bX		X	X	X	
16 August	C	X	X^b		X	X	X		X^bX				X^b		X	X				X	
	A		X^b		X	X			X^bX		X^b							X		X	
	G	X	X^bX		X	X			X^bX				X			X^bX^bX				X^b	
13 September	C	X	X	X		X^bX			X^b					X		X^cX^bX			X		
	A	X	X^bX		X	X^cX			X^bX			X	X		X	$X^bX^bX^bX$					
	G		X^c		$X^bX^bX^bX$				X	X			X		X	X^bX^b					
11 October	C		X^b			X^b			X^bX^b												
	A		X^c		X	X^b			X^bX		X							X			
	G		X^c		X	X^b			X^cX									X			

[a] C - Control Plantation; A - Antenna Plantation; G - Ground Plantation
[b] detected in two or more of replicate samples/plantation
[c] predominant type in two or more of replicate samples/plantation

respectively. Approximately 60 percent of all isolates, representing over 50 percent of the morphotypes, could degrade all three substances. These results are similar to those found with streptomycete isolates from the 1987 sampling season.

Projected Work

Analysis in 1989 will continue to deal with determination of streptomycete levels and morphotype numbers associated with washed red pine type 3 mycorrhizal fine roots. There will be no change in sampling or detection methods or in the numbers of samples analyzed per plantation. Increased emphasis will be placed on covariate analysis of the data in modeling environmental/biological variables effecting streptomycete population differences between plantation subunits, sampling dates, and years.

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GLOSSARY

Actinomycete	A large group of true bacteria, characterized by a mycelial vegetative structure.
Basal Area	The area of the cross section of a tree at DBH.
Biomass	The amount of living matter in a unit area.
DBH	Diameter at breast height. Average stem diameter, outside bark, measured 4.5 feet above the ground.
Ectomycorrhizae	The type of mycorrhizae in which the fungus component grows only intercellularly within its host root, and produces an external mantle.
Habitat Type	Land areas potentially capable of producing similar plant communities at maturity.
Litter	Dead, largely unincorporated leaves and other plant parts on the forest floor.
Mycorrhizae	A mutually beneficial association between plant roots and certain highly specialized parasitic fungi.
Mycorrhizoplane	The rhizoplane of mycorrhizae.
Mycorrhizosphere	The rhizosphere of mycorrhizae.
NESS	National Earth Satellite Service.
NOAA	National Oceanographic and Atmospheric Administration.
Nutrient Flux	In litter decomposition, the balance between the rates of nutrient movement into and out of decomposing litter.
Rhizoplane	The actual surface of plant roots, together with any closely adhering particles of soil or debris.
Rhizosphere	The narrow zone of soil subject to the influence of living roots.
Streptomycete	Members of the genus Streptomyces, a group of actinomycetes which reproduce by forming spores.

A1

Figure A1. Predicted (P) versus actual (A) mass remaining for bulk maple samples in the hardwood stands when the simple exponential regression is estimated.

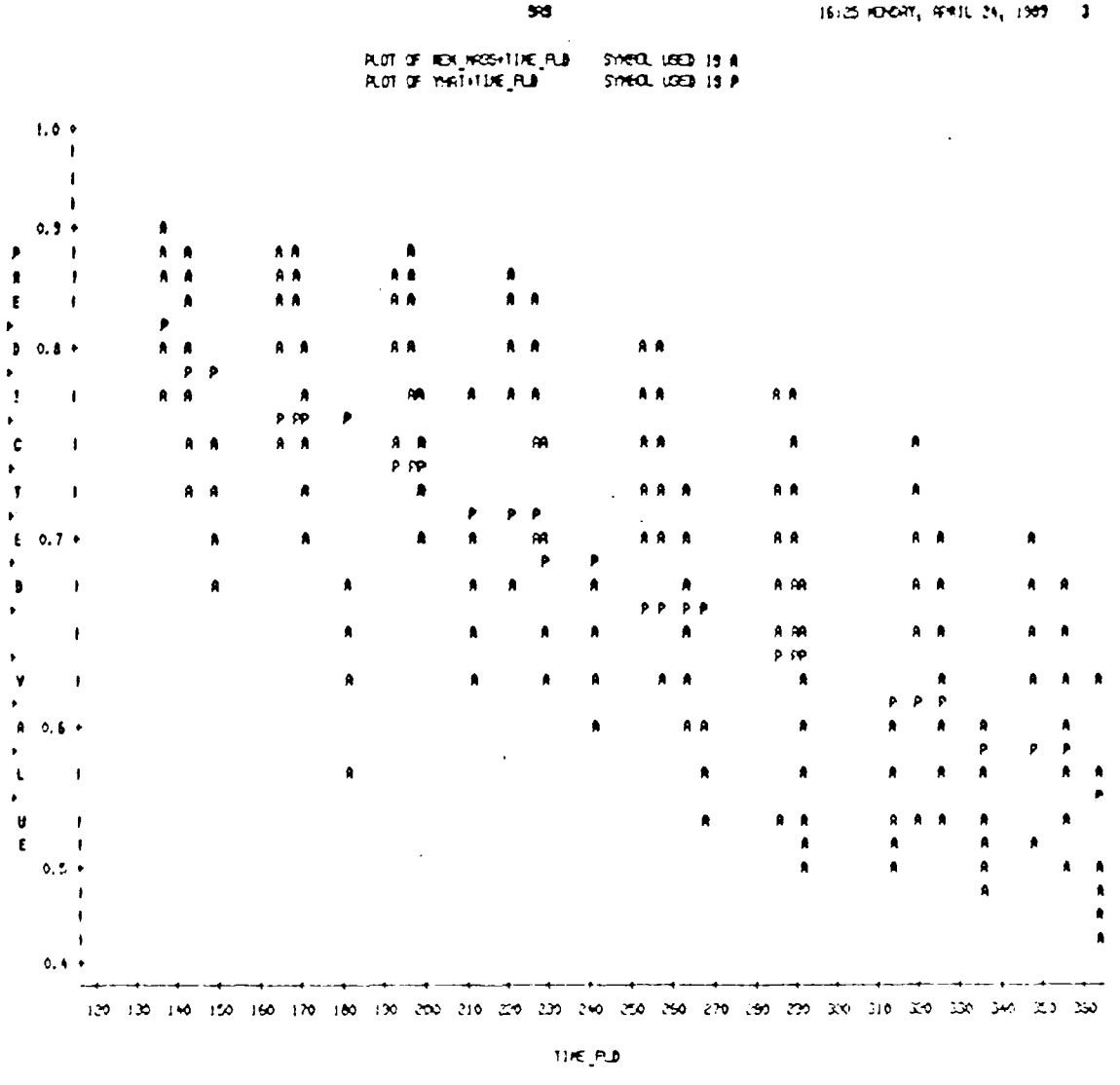


Figure A2. Residual distribution over time for bulk maple samples in the hardwood stands when the simple exponential regression is estimated.

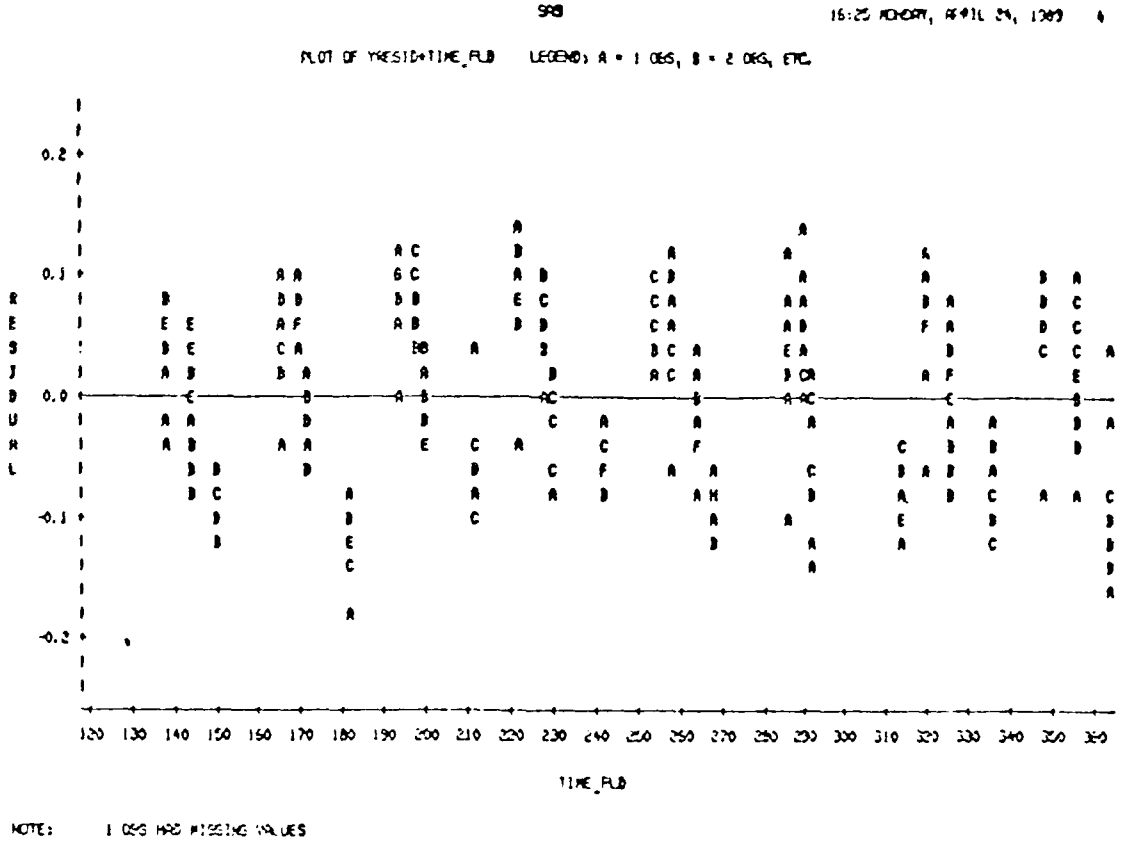
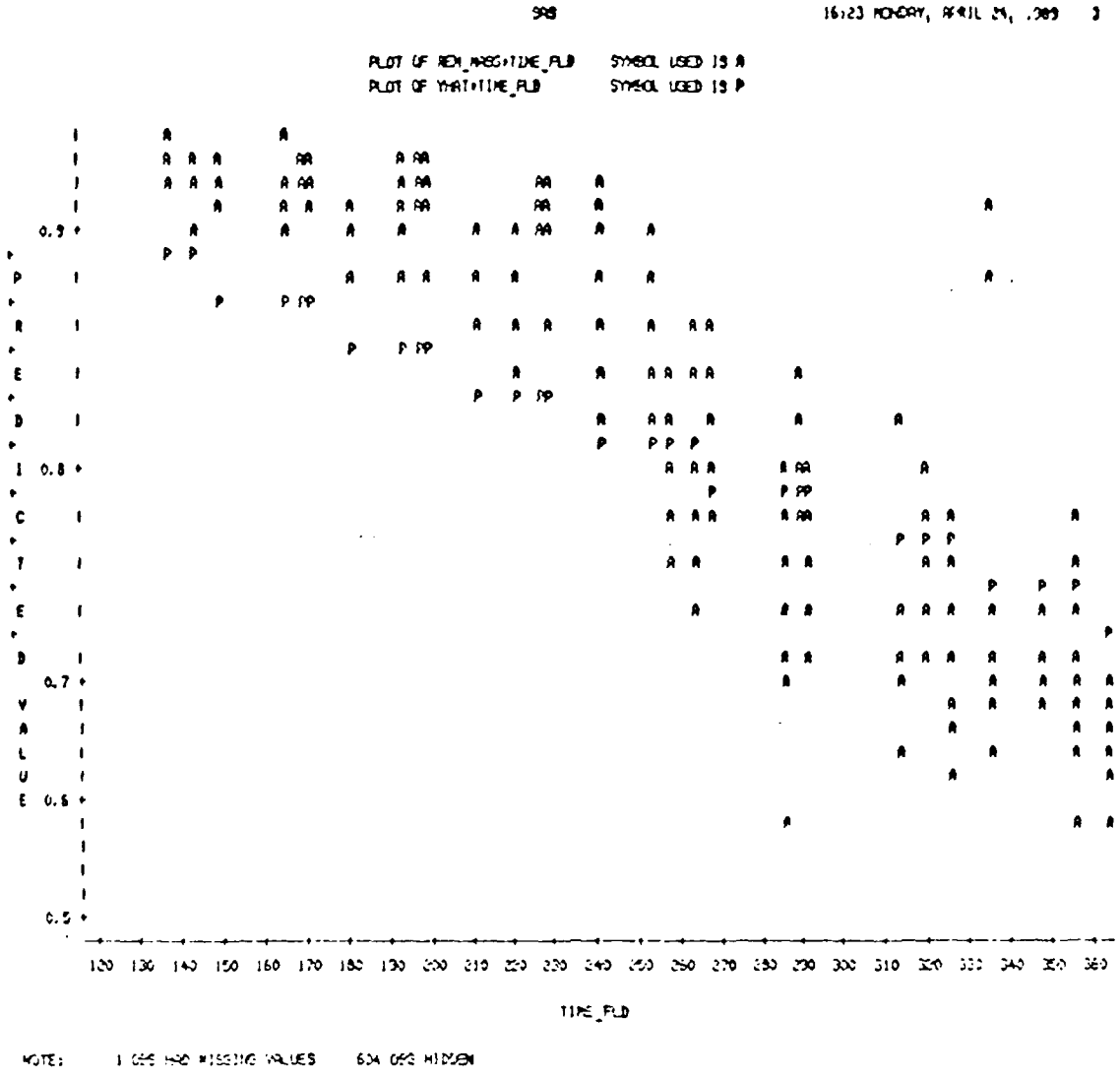
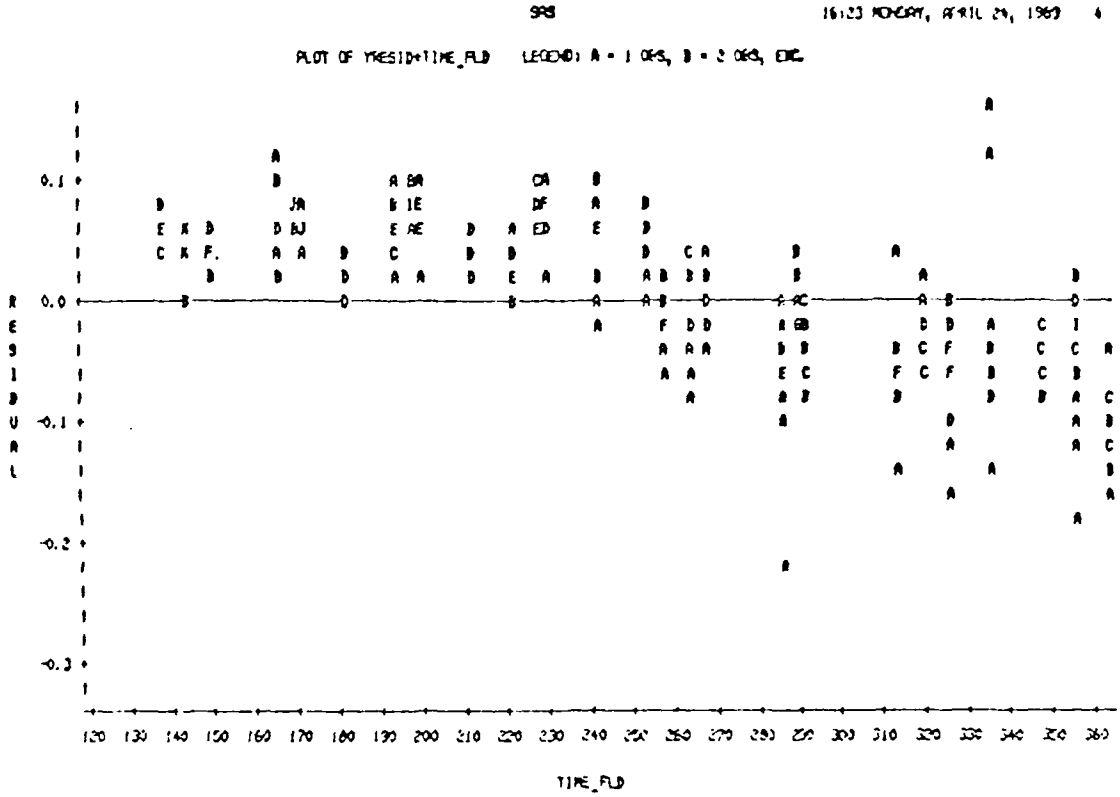


Figure A3. Predicted (P) versus actual (A) mass remaining for bulk oak samples in the hardwood stands when the simple exponential regression is estimated.



A4

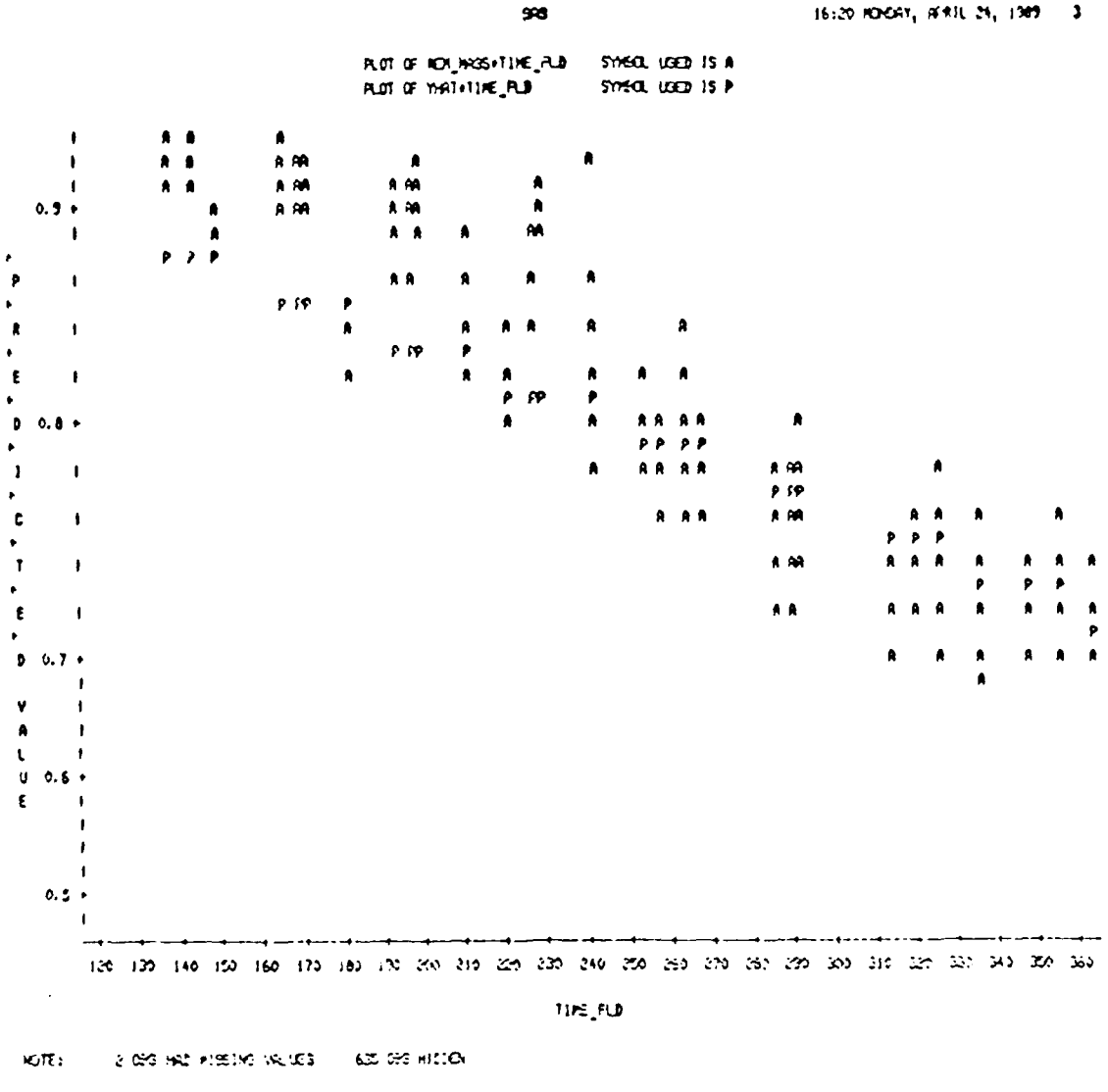
Figure A4. Residual distribution over time in the field for bulk oak samples in the hardwood stands when the simple exponential regression is estimated.



NOTE: 1 OBS HAD MISSING VALUES

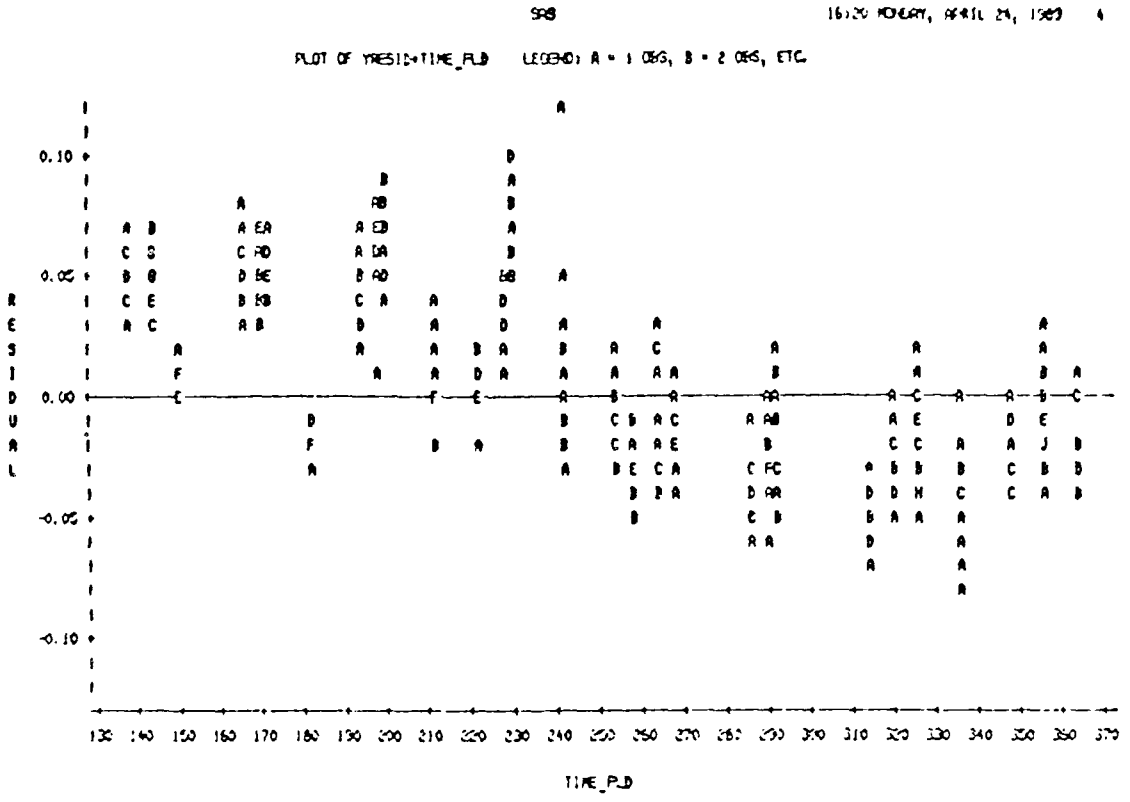
A5

Figure A5. Predicted (P) versus actual (A) mass remaining for bulk pine samples in the hardwood stands when the simple exponential regression is estimated.



A6

Figure A6. Residual distribution over time in the field for bulk pine samples in the hardwood stands when the simple exponential regression is estimated.



NOTE: 2 OBS HAD MISSING VALUES